IMAGES OF THE MOON FROM CHANDRAYAAN-1

The Moon image from Cartosat-2A PAN Camera

Space Applications Centre
Indian Space Research Organisation
Govt. of India
Ahmedabad-380 015.

2011

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Principal Investigator
A. S. Kiran Kumar

Contributors
B. Gopala Krishna
Amitabh
A. S. Arya
I. M. Bahuguna
R. Phani Rajsekhar
Prakash Chauhan
Jignesh Bhatt

Advisors
P. K. Srivastava
Ajai

Design and Composition
Puneet Swaroop.
S. Ramdass

Concept
R. R. Navalgund

K. Radha Krishnan
Chairman, ISRO

FOREWORD

Ahmedabad
August, 2010

(K. Radha Krishnan)

भारत सरकार
अन्तरीक्ष विभाग
अन्तरिक्ष उपयोग केन्द्र
आंबावाडी विस्तार डाक घर,
अहमदाबाद - 380015. (भारत)
दुरभाष: +91-79-6912000, 6915000
फैक्स :

Government of India
Department of Space
SPACE APPLICATIONS CENTRE
Ambawadi Vistar P.O.
Ahmedabad-380 015. (India)
Telephone : +91-79-6912000, 6915000
Fax :

Ranganath R. Navalgund
Director

PREFACE

Exploration of the moon to understand its origin and evolution and to identify exploitable resources, if there are any, using space vehicles carrying a variety of instruments has been a very fascinating pursuit of many space agencies. Such a mission was conceived by Dr. K. Kasturirangan, the then Chairman, ISRO in late 1990's and a detailed study report was brought out by Dr. George Joseph, Prof. N. Bhandari and many others. This was projectised in 2003 and was realised under the stewardship of Shri Madhavan Nair, the then Chairman, ISRO (2003-2009) ensured its realization. The Indian mission to the moon, Chandrayaan-1 was launched on October 22, 2008. The successful launch and the subsequent availability of high quality data from Chandrayaan-1 has provided scientists an opportunity to observe the moon at a very high resolution with a variety of payloads operating in different spectral ranges. Both near and far side images acquired by Chandrayaan-1 mission with the help of different payloads onboard are providing vital information about the surface features and clues to understand history of formation of the Moon. In particular, the two payloads viz., Terrain Mapping Camera (TMC) and Hyper-spectral Imager (HySI) onboard Chandrayaan-1 developed by the Space Applications Centre have provided valuable data for studying geology, geomorphology, mineralogical studies and for preparation of the three dimensional moon atlas. Some of such images depicting unique and important geomorphological features including certain mineralogical aspects and polar mosaics, have been compiled and brought out in the form of this atlas.

I would like to place on record my appreciation to the team at the Space Applications Centre for completing this voluminous task. We shall be happy to receive feedback from the viewers of this atlas on the utility of this image collection.

Ahmedabad
December 23, 2010

(Ranganath R. Navalgund)

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अन्तरीक्ष विभाग
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Ambawadi Vistar P.O.
Ahmedabad-380 015. (India)
Telephone : +91-79-6912000, 6915000
Fax :

B. Gopala Krishna
Group Director
SPDCG, SIPA.

ACKNOWLEDGEMENT

The Chandrayaan-1 spacecraft viewed the lunar surface from 100/200 km circular polar orbit. On 14 November, the Moon Impact Probe (MIP) carrying Indian national flag was ejected from the Chandrayaan-1 spacecraft and it hard landed on the lunar surface near the South Polar Region. The Chandrayaan-1 mission is aimed at three dimensional terrain mapping of lunar surface in high resolution, geological, mineralogical and chemical mapping.

The moon surface consists of two major types of terrain called highland or terrae (brighter) and Seas or maria (darker). The highland consists of light grey, high standing blocks of terrain covered by a seemingly endless sequence of overlapping craters. The dark maria cover about 16% of the lunar surface. The study of various lunar features is very important for the purpose of distinction between them. This image collection provides the glimpses of the moon surface at very high scale.

We are extremely thankful to Dr. R.R. Navalgund, Director, Space Applications Centre, for his initiative and conceptulisation of this image collection; constant encouragement, guidance and for valuable suggestions during this work. We express our thanks to Shri A.S. Kiran Kumar, Associate Director, SAC & PI for TMC and HySI instruments, Dr. P K Srivastava, Deputy Director, Signal and Image Processing Area, Space Applications Centre, Dr. J S Parihar, Deputy Director, Remote Sensing Applications Area, Dr. Ajai, Group Director, Marine and Earth Sciences Group for their support and guidance in executing this task.

We are also grateful to Shri. S K Shiva Kumar, Director ISTRAC for his untiring efforts in providing the support in (i) getting data at SAC and (ii) polar mosaicing activity. Special thanks are due to team members of Indian Space Science Data Centre (ISSDC), for providing data and the technical support.

We gratefully acknowledge, Principal Scientist Prof. J. N. Goswami (and Director, Physical Research Laboratory), Project Director, M. Annadurai and the Mission Team for providing an excellent mission Chandrayaan-1 with state of the art payloads yielding good quality imagery for this compilation.

We express our sincere thanks to Shri S. Ramdass, Head, Projects and Progress Monitoring Division (PPMD), and Dr. Puneet Swaroop, Scientist/Engineer, PPMD/PPG, Space Applications Centre for their innovative ideas and untiring effort in designing and composing this image collection.

We are thankful to members of (i) Satellite Photogrammetry and Digital Cartography Group (ii) Chandrayaan-1 DP and Payload Operations Centre especially to Ms. Sunanda Trivedi for providing support in some of the data preparation, and to Dr. Arvind K Singh for providing the MIP impact point imagery and (iii) Marine and Earth Sciences Group especially Sh. Anish Mohan, Sh. Th. Guneshwar Singh and Sh. Satadru Bhattacharya for their extensive support during the preparation of this image collection.

(B. Gopala Krishna)

Ahmedabad

December, 2010

SUMMARY

Chandrayaan-1, the first planetary mission of ISRO to the Moon is aimed at three dimensional terrain mapping of lunar surface in high resolution, geological, mineralogical and chemical mapping and also help in studying evolutionary history of the Moon. Chandrayaan-1 has eleven scientific payloads which include six from India viz. Terrain Mapping Camera (TMC), Hyperspectral Imager (HySI), High Energy X-Ray Spectrometer (HEX), Lunar Laser Ranging Instrument (LLRI), Moon Impact Probe (MIP), Sub KeV Atom Reflecting Analyser (SARA) in collaboration with sweden and Japan; the remaining are from various global institutes viz. Moon Mineralogical Mapper (M3) from USA, Radiation Dose Monitoring Experiment (RADOM) from Bulgaria, Chandrayaan-1 X-Ray experiment (C1XS) from ESA, Miniature Synthetic Aperture Radar (MiniSAR) from USA, Infrared Spectrometer (SIR-2) from Germany.

The moon surface consists of two major types of terrain called highland or terrae (brighter) and Seas or maria (darker). The highland consists of light grey, high standing blocks of terrain covered by a seemingly endless sequence of overlapping craters. The dark maria cover about 16% of the lunar surface. The study of various lunar features is very important for the purpose of distinction between them.

Space Applications Centre (Indian Space Research Organization) has made a sincere effort to harness Chandrayaan-1 data especially TMC and HySI to study different types and formation of features present on the moon surface and it's geological and geomorphologic importance. This has led to the development of baseline collection of images consisting of unique and important features including some of the mineralogical aspects, MIP traces polar mosaics that can be a foundation for more detailed Chandrayaan-1 Atlas in future.

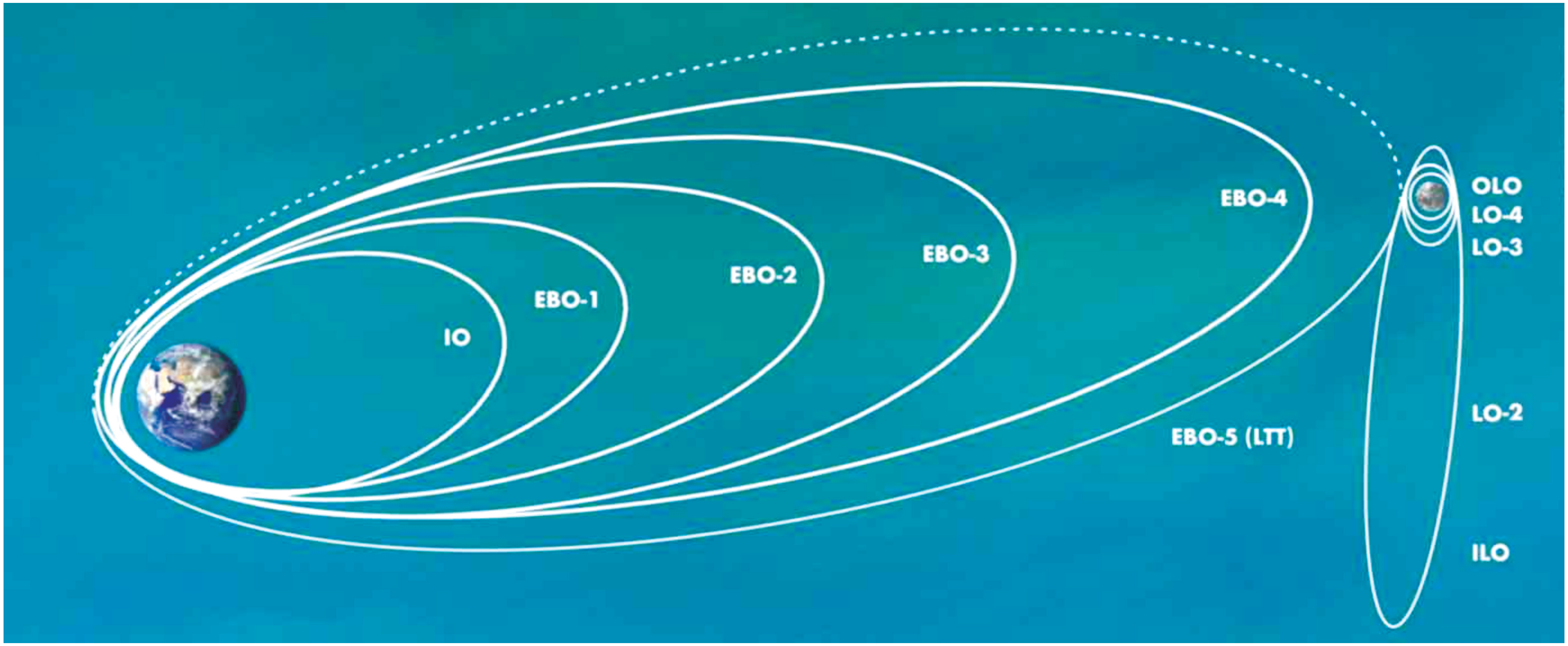
This image collection provides the glimpses of the moon surface at very high scale basically from TMC and HySI payloads. Besides the features, this also shows some of the initial images taken by TMC of Chandrayaan-1 enroute the moon, when it imaged the earth and the moon from a distance of 70000 km and 311200 km respectively. Exclusive earth images taken from the orbit of the moon on two occasions viz. to show the Indian subcontinent and the local solar eclipse on 22nd July 2009 (which also include a part of the moon) are also provided as highlights of the sensor quality. The coverage maps of TMC in equatorial and Polar Regions show the actual coverage patterns of the TMC.

In the initial sections, the morphological features covered in this image collection are wrinkle ridges, conical hills Craters (types, morphology and chronology) & secondary craters within craters. Mountains represent highlands. Plain land consists of younger craters, lava flows, .Escarpments indicating different levels of volcanic flows, Geological features include lineaments, faults, grabens, various forms of rilles. Special features like Apollo landing sites (15 and 17) along with the surface visualization in 2.5 D mode (generated using the DEM derived from the TMC triplet) and an orthoimage map of an area in 1:25000 scale show the capability of TMC imagery. The Moon Impact Probe (MIP) imagery and the estimated impact point location are also provided in various plates of this image collection along with the comparison with TMC. This gives an idea of the Moon imaging system as well as the exact location of the impact.

In the last section some of the mineralogical studies carried out at Space Applications Centre using Hyperspectral imagery are provided. This includes studies like detection of lunar rock types, surface composition of Titanium and Iron rich regions of Orientale basin, Reiner Gamma formation, Titanium distribution within Crater Le Monnier, Mare Serenitatis and Dark Haloed Craters or Localized dark mantling deposits in Mare Nectaris.

Contents

Chandrayaan - 1 Mission Profile

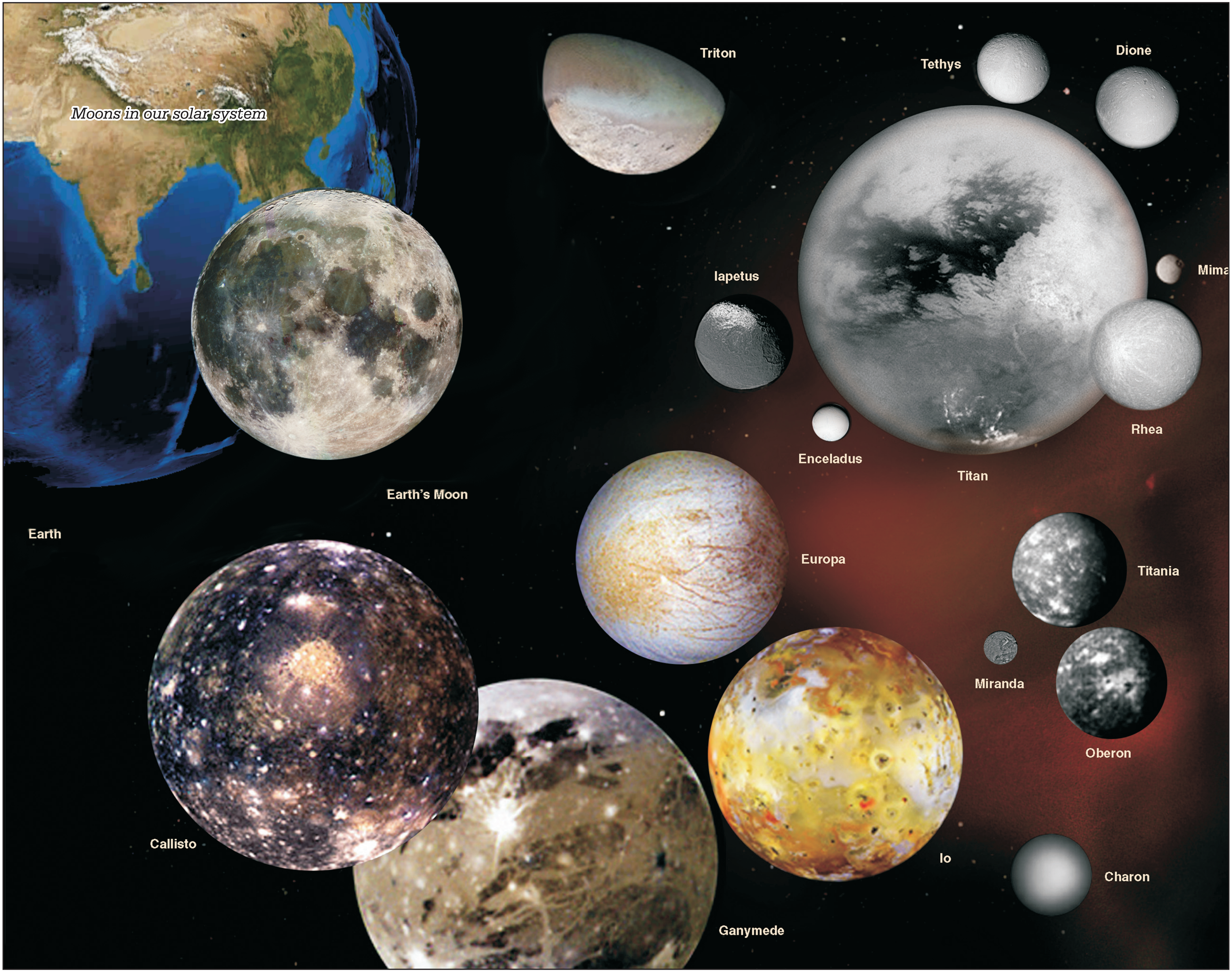


IO: Initial (Earth) Orbit:	255 km x 22,860 km
EBO:	Earth Bound orbit
EBO-1:	apogee at 37,900 km
EBO-2:	apogee at 74, 715 km
EBO-3:	apogee at 164,600 km
EBO-4:	apogee at 267,000 km
EBO-5 (LTT-Lunar Transfer Trajectory):	apogee at 380,000 km

ILO (Initial Lunar Orbit):	504 km x 7502 km
LO:	Lunar Orbit
LO-2:	200 km x 7502 km
LO-3:	182 km x 255 km
LO-4:	100 km x 183 km
OLO (operational Lunar Orbit):	100 km x 100 km

Man and the Moon

The surface of the moon and the moon's cycle around earth must have been observed by human being since time immemorial. But ancient Greeks were able to determine the moon's motion, distance from earth and its size. Anaxagoras (500-428 B.C.) and Aristotle (384-322 BC) recognized that moon was solid object illuminated by the sun. It was Galileo who in the beginning of 17th century first observed the surface of the moon through telescope. He noted the topographic irregularities in the form of undulations and the craters. He called the darker areas on the moon surface as Maria which is Latin for sea and the lighter area as terrae which means land in Latin. This was the first classification of the surface of the moon. Galileo was followed by numerous observers who made telescopic observations until the first spacecraft mission went to the moon in early 1960. The telescopic observations were supplemented by Soviet Union's Luna Space craft, USA's Ranger and Surveyor Missions. The landing of an American Space craft eagle (Flight Apollo 11) in the sea of Tranquillitatis on July 20 1969 was a milestone in human history and signaled the start of era of space exploration. It was followed by additional five trips. Since then many other missions such as Clementine , Lunar Prospector , SMART-1 mission of European Space agency (ESA) , Lunar –A , SELENE by Japan , CHANG'E by China, Chandrayaan -1 by India and Lunar Reconnaissance Orbiter (LRO) by USA have added a wealth of data which have opened up new vistas for mankind in the exploration and understanding of universe. Experiments using sophisticated sensors have been conducted on the lunar surface. These ranges from passive seismo meters, magneto meters, solar wind spectrometer, Laser ranging retro reflector, sensor for gravity measurement and cosmic ray detection. The sensors which have acquired data by orbiting around the moon include gamma ray spectrometer, laser altimeters, X -ray fluorescence, lunar sounder, TMC, HySI, M3, LLRI etc. By these missions it has been possible to see the far side of the moon also. One of the important milestone was selenology; bringing rock samples from the moon to earth and finding their ages of the lunar crust using radio isotopic methods. The multispectral images and recent discovery of water in the sunless deep craters is the first important news of 21st century in interplanetary exploration. The features imaged by Chandrayaan TMC camera , stereo imaging of the moon surface , mineralisation by HySI etc will further boost up the efforts to understand our nearest neighbour and in future how this moon's surface could be utilised for launching other planetary missions with establishing a lunar base..



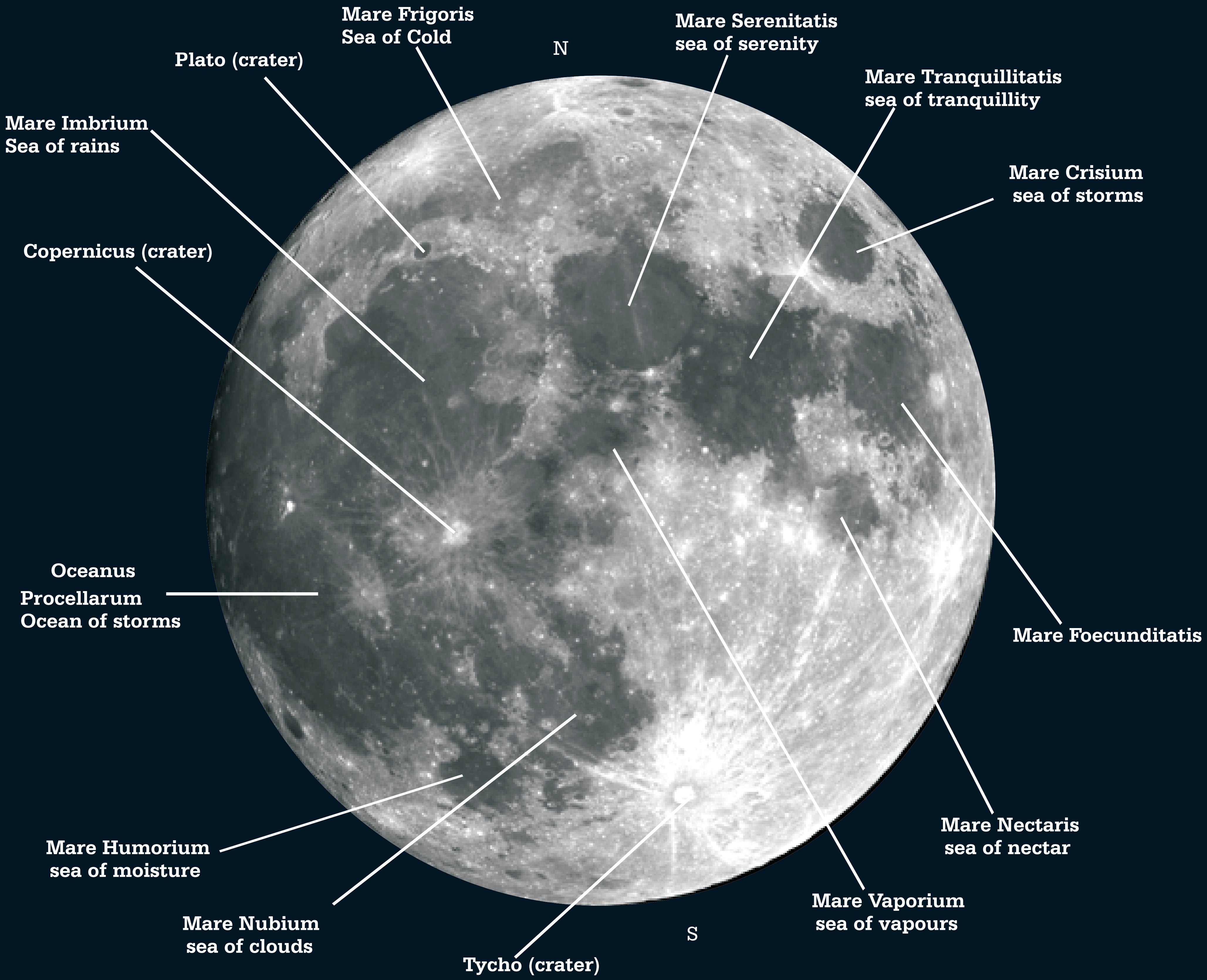
Moons in our solar system
Triton
Tethys
Dione
Iapetus
Mima
Enceladus
Titan
Rhea
Earth's Moon
Earth
Europa
Titania
Miranda
Oberon
Callisto
Io
Charon
Ganymede

The Moon : Basic Facts

Universe began about 13.7 billion years ago with a cosmic explosion called the big bang. Universe is still expanding and thinning out to form galaxies and stars. Our solar system formed and evolved in the last 4.5 billion years and Nebular hypotheses explains this. Nebulae are the rotating clouds or fog of gases that gave rise to form of different planets around earth. The moon is believed to be result of giant impact hypothesis. A mars sizes body collided with earth and created shower of debris. From both earth and impacting body and the moon aggregated from this debris. According to this theory earth reformed as a body with an outer molten layer hundreds of kilometers thick – a magma ocean.. The huge impact sped up earth's rotation and changed its spin axis to 23° inclination with orbit plane. The rotational period of the moon matches with its period of revolution so that same side of the moon always faces the earth. the revolution of earth and rotation of the moon around earth keeps a direct control on water of earth' s ocean (tides). Moon's face is never obscured by lunar clouds which indicates that the moon does not have an atmosphere because the moon lacks water and other volatiles such as Co2 or methane. Mass of the moon is too small to generate a sufficient gravitational force to retain gases such as Helium, Nitrogen, Neon and Argon.

The distance of the Moon from the Earth is about 384,403 km . The Moon revolves around the earth at an average speed of 3,700 km/h and completes one revolution in an elliptical orbit around earth in 27 days 7 hours 43 minutes 11.5 seconds. For the Moon to go from one phase to the next similar phase, or one lunar month, requires 29 days 12 hours. The diameter of earth's Moon is about 3,480 km (about 2,160 mi), or about one-fourth that of Earth and volume is about one-fiftieth that of earth. The mass of earth is 81 times greater than the mass of the Moon while the average density of the Moon is 3.34g/cm3 which is only three-fifths of the earth. Inclination of orbiting plane to ecliptic is 27.33 degree. temperature on the moon surface ranges from -158° to 130 °C. The gravitational pull at the lunar surface is only one-sixth, that of Earth. The Moon has no liquid-water and essentially no atmosphere, so no weather exists to change its surface; yet it is not totally inert.

Maximum variation in the albedo of the lunar surface are observed during the full Moon (zero phase angle). The average albedo for the nearside of the moon is low (about 0.07, or about 7%)compared with that of the earth (average 0.39) or Venus (0.7-0.9).The Maria typically have very low albedo values between 0.09 and 0.12.



Features on the Moon

The Moon : Geology & Geomorphology

The understanding of geology and geomorphology of the moon which stands today can be briefly described as follows:

1 Mare: The dark areas observed even with the naked eye are composed of basaltic lava flow with ages around 4 billion years. These Iron rich lava bears an order of magnitude more fluid than terrestrial lavas accounting for large smooth Maria and absence of central volcanic cone . Mare region is less cratered than highland areas as most of the craters are modified by volcanic interference. Most of the mare region is exposed on near side of the moon.

2 Highlands: Lunar highlands are mainly composed of Anorthosite, a silicate rich in Calcium and Aluminum. The highland plains are composed of mainly ejecta sheets formed from the large basin impact. Highlands cover almost 70 % of lunar surface, which have higher relief variations than mare region thus making mare a smooth plain surface. Most of the highlands are located in far side of the moon.

3 Cratering: The entire lunar surface is characterized by circular to semicircular features ranging in size from microscopic pit to large basins with hundreds of kilometers in diameter. Mostly the craters are of impact origin of the large basins appear to be similar to calderas. The overall appearance and morphology of lunar crater varies with their size and age. Based on the observations from Chandrayaan TMC data, the following type of craters can be identified:

a) Craters with flat bottom, central mount and concentric ridges.

b) Perfectly bowl shaped craters with raised rings.

c) Craters with sharp rims and steep inner walls appearing like funnels.

d) Craters appearing very bright with solidified splash of ejecta.

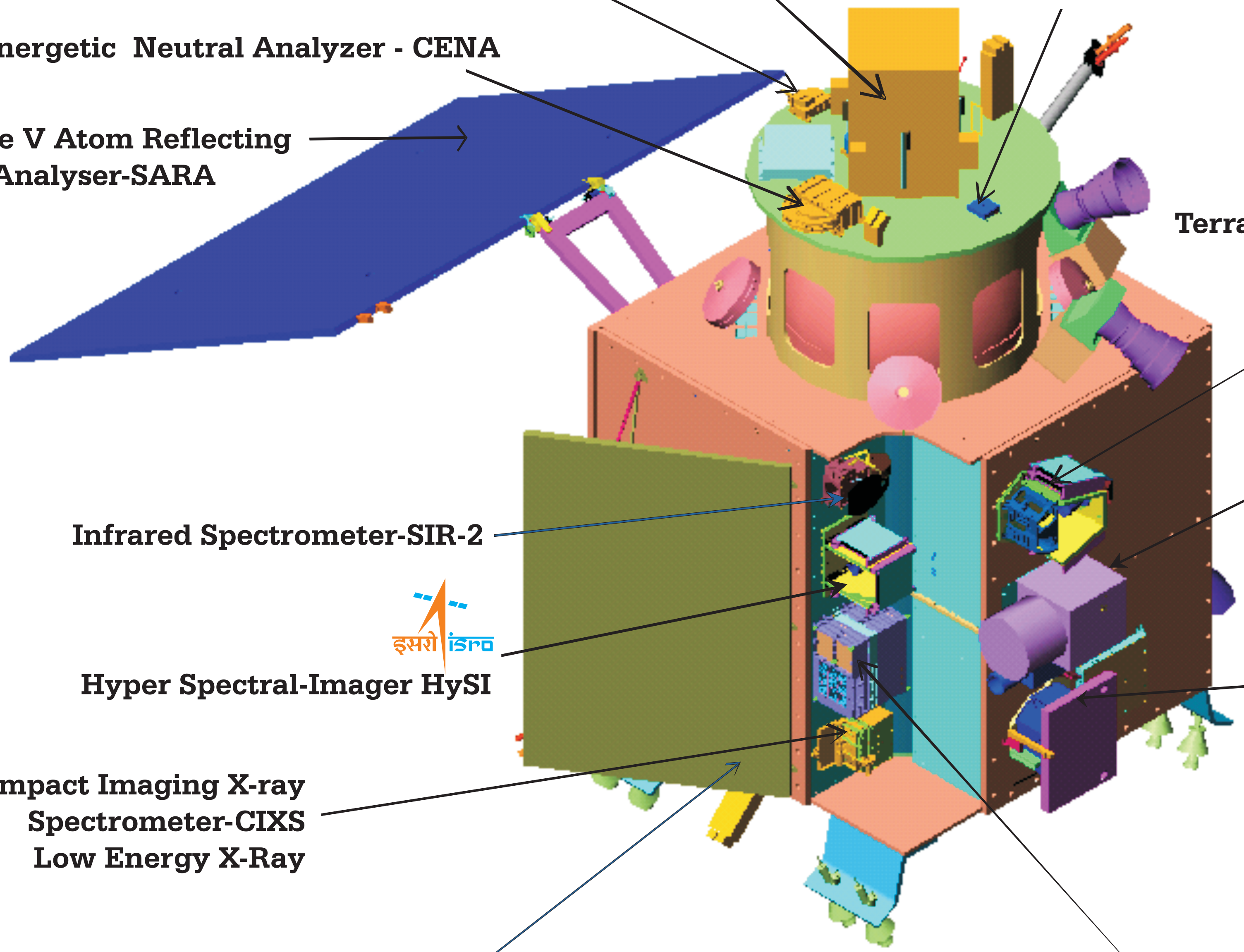
e) Craters with unusually large diameters

4. High land mare mixing: There are certain regions which are characterized by a topography which is formed due to the contact of Highland and mare regions

5. Non mare Volcanism: There are regions in the highlands which also characterized volcanic rocks which are distinct from mare basalt in it's composition.

6. Tectonic features: There are certain topographic features which are indicative of tectonic deformation. Though there are little or no direct evidences of any global lunar stress, many features of local extent indicative of vertical lithospheric failure are observed in the form of unique lunar morphological features. These are basins ring structures, mare ridges, rilles, graben and escarpments.

THE CHANDRAYAAN - 1 PAYLOADS



Moon Impact Probe -MIP

Solar Wind Monitor- SWIM

Radiation Dose
Monitor-RADOM

Chandrayaan Energetic Neutral Analyzer - CENA

Sub ke V Atom Reflecting
Analyser-SARA

Terrain Mapping Camera-TMC

Lunar Laser Ranging
Instrument-LLRI

Infrared Spectrometer-SIR-2

Hyper Spectral-Imager HySI

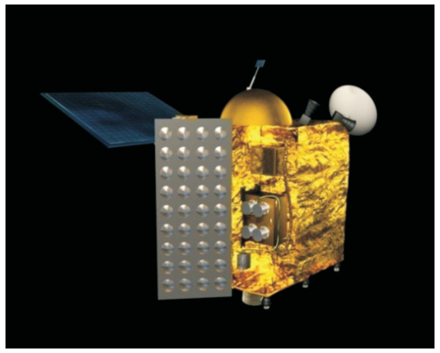
Moon Mineralogy-Mapper

Compact Imaging X-ray
Spectrometer-CIXS
Low Energy X-Ray

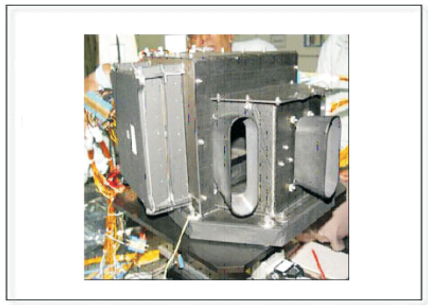
Miniature Synthetic Aperture
Radar-MINISAR

High Energy X-RAY-HEX

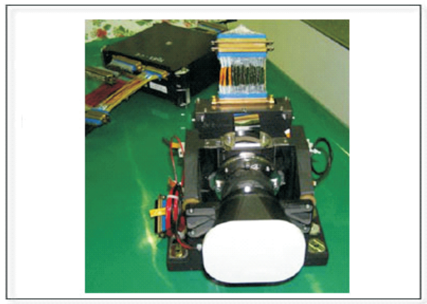
Chandrayaan-1 - Mission & Payloads



Chandrayaan-1 Spacecraft



TMC



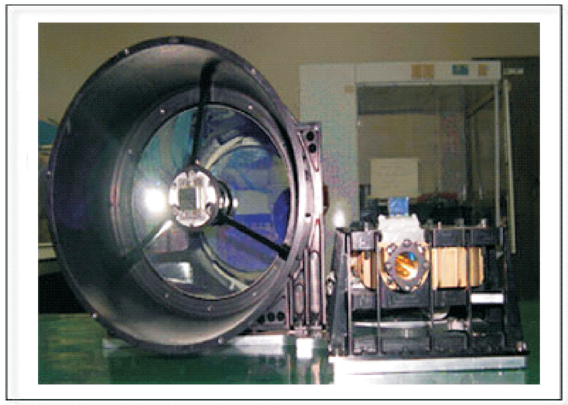
HySI

Chandrayaan-1 spacecraft was launched from the Satish Dhawan Space Centre, SHAR, Sriharikota by PSLV-XL (PSLV-C11) on 22 October 2008. The spacecraft viewed the lunar surface from 100 km circular polar orbit. On 14 November, the Moon Impact Probe (MIP) carrying Indian national flag was ejected from the Chandrayaan-1 spacecraft and it hard landed on the lunar surface near the south polar region. The Chandrayaan-1 mission is aimed at three dimensional terrain mapping of lunar surface in high resolution, geological, mineralogical and chemical mapping and also help in studying evolutionary history of the Moon. Chandrayaan-1 has eleven scientific payloads which include six from India; remaining from USA, UK, Bulgaria, Sweden, Japan and Germany.

The aim of Terrain Mapping Camera (TMC) developed at SAC (ISRO), is to map the topography of both near and far side of the Moon and prepare a 3-dimensional atlas with high spatial resolution of 5 m. Such high resolution mapping of complete lunar surface will help to understand the evolution processes and allows detailed study of regions of scientific interests. Further, the digital elevation model available from TMC would improve upon the existing knowledge of Lunar Topography. TMC acquires images in the panchromatic spectral region of 0.5 to 0.85 μm, with a spatial/ ground resolution of 5 m and swath coverage of 20 km. The camera is configured for imaging in the push broom mode, with three linear 4k element detectors in the image plane for fore, nadir and aft views, along the ground track of the satellite. The fore and aft view angles are ±25° respectively with respect to Nadir. TMC measures the solar radiation reflected/scattered from the Moon's surface. The dynamic range of the reflected signal is quite large, represented by the two extreme targets – fresh crust rocks and mature mare soil. TMC uses Linear Active Pixel Sensor (APS) detector with in-built digitizer. Single refractive optics will cover the total field of view for the three detectors. The optics is designed as a single unit catering to the wide field of view (FOV) requirement in the direction along the ground track. The incident beams from the fore (+25°) and aft (-25°) directions are directed on to the focusing optics, using mirrors. Modular camera electronics for each detector is custom designed for the system requirements using FPGA. The dimension of TMC payload is 370 mm x 220 mm x 414 mm and mass is 6.3 kg.

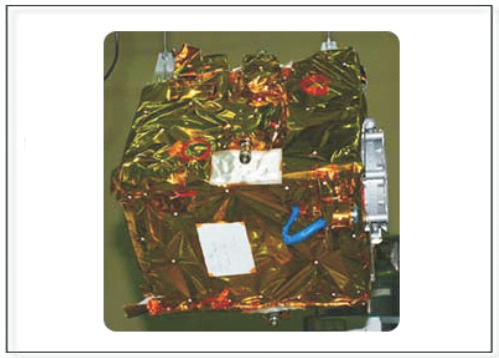
Scientific objective of the Hyper Spectral Imager (HySI) camera, developed at SAC (ISRO) is to obtain spectroscopic data for mineralogical mapping of the lunar surface. The data from this instrument helps in improvement of the previous available information on mineral composition of the surface of the Moon. Also, the study of data in deep crater regions/central peaks, which represents lower crust or upper mantle material, will help in understanding the mineralogical composition of the Moon's interior. The uniqueness of the HySI is in its capability of mapping the lunar surface in 64 contiguous bands in the VNIR, the spectral range of 0.4-0.95 μm region with a spectral resolution of better than 15 nm and spatial resolution of 80 m, with swath coverage of 20 km. HySI collects the Sun's reflected light from the Moon's surface through a tele-centric refractive optics and focuses on to an APS area detector for this purpose. The payload mass is 2.5 kg and its size is 275 mm x 255 mm x

Scientific Objective of the Lunar Laser Ranging Instrument (LLRI) developed at LEOS (ISRO) is to provide ranging data for determining the range between the spacecraft and the lunar surface. LLRI works on the time-Of-Flight (TOF) principle. In this method, a coherent pulse of light from a high power laser is directed towards the target whose range is to be measured. A fraction of the light is scattered back in the direction of the laser source where an optical receiver collects it and focuses it on to a photoelectric detector. By accurately measuring the roundtrip travel time of the laser pulse, highly accurate range/spot elevation measurements can be made. LLRI consists of a 10 mJ Nd:YAG laser with 1064 nm wave source operating at 10 Hz pulse repetition mode. The reflected laser pulse from the lunar surface is collected by a 200 mm Ritchey-Chrétien Optical receiver and focused on to a Silicon Avalanche Photo detector. The output of the detector is amplified and threshold detected for generating range information to an accuracy <5m. Four constant fraction discriminators provide the slope information in addition to range information. The different modes of operation of LLRI and the range computations from the detector output are controlled and computed by a FPGA based electronics. The processed outputs of LLRI are used for generating high accuracy lunar topography. The payload mass is 11.37 kg with base plate.



LLRI

The moon impact probe (MIP) of 35 kg mass was attached at the top deck of the main orbiter and was released during the final 100 km x 100 km orbit at a predetermined time to impact at a pre-selected location. During the descent phase, it is spin-stabilized. The total flying time from release to impact on the moon is around 25 minutes. The primary objective of this probe is to demonstrate the technologies required for landing at a desired location on the Moon and to qualify some of the technologies related to future soft landing missions in addition to the scientific exploration of the Moon from close range.



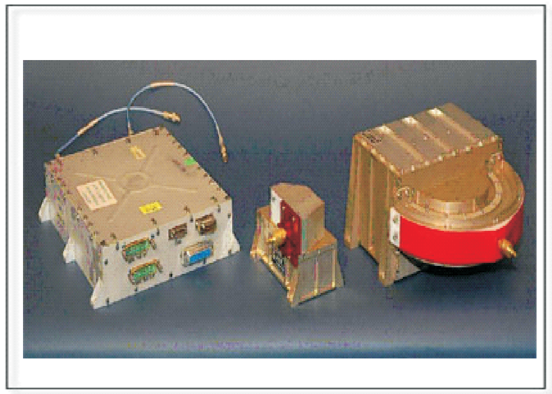
MIP

The Moon Mineralogy Mapper (M3) payload is from Brown University and Jet Propulsion Laboratory, USA through NASA. The primary Science goal of M3 is to characterize and map lunar surface mineralogy in the context of lunar geologic evolution. This translates into several sub-topics relating to understanding the highland crust, basaltic volcanism, impact craters, and potential volatiles.The M3 scientific instrument is a high throughput push broom imaging spectrometer, operating in 0.7 to 3.0 μm range. It measures solar reflected energy, using a two-dimensional HgCdTe detector array. The M3 payload provides the datasets at sampling interval of 10 nanometers, spatial resolution of 70 m/pixel (from 100 km orbit) with a swath coverage of 40 km (from 100 km orbit).

M3

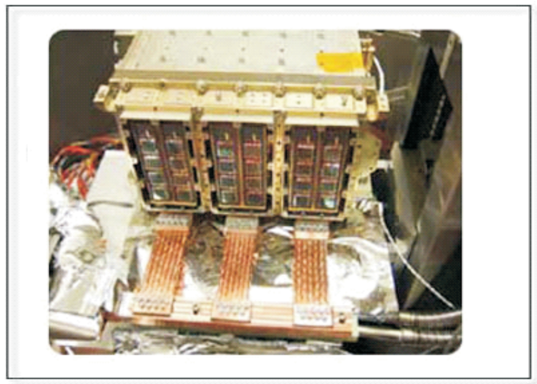
RADOM

Radiation Dose Monitor Experiment (RADOM) from Bulgaria, characterises the radiation environment qualitatively and quantitatively in near lunar space, in terms of particle flux, dose rate and deposited energy spectrum. The general purpose of RADOM is to study the radiation hazards during the Moon exploration. Data obtained will be used for the evaluation of radiation environment and radiation shielding requirements for future manned lunar missions. RADOM is a miniature spectrometer-dosimeter containing one semiconductor detector of 0.3 mm thickness, one charge-sensitive preamplifier and two micro controllers. The detector weighs 139.8 mg. Pulse analysis technique is used for obtaining the deposited energy spectrum, which is further converted to the deposited dose and flux in the silicon detector. The exposure time for one spectrum is fixed at 30 s. The RADOM spectrometer measures the spectrum of the deposited energy from primary and secondary particles in 256 channels. RADOM mass is 160 g.



SARA

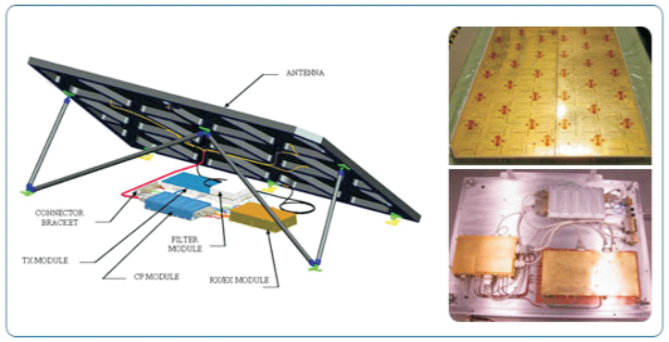
Sub keV Atom Reflecting Analyser (SARA) is through ESA, from Swedish Institute of Space Physics, Sweden and Space Physics Laboratory, Vikram Sarabhai Space Centre, ISRO. SARA provides the images of the Moon surface using low energy neutral atoms as diagnostics in the energy range 10 eV - 3.2 keV. The objective of SARA is to image the moon's surface composition including the permanently shadowed areas and volatile rich areas, the solar wind-surface interaction, lunar surface magnetic anomalies and the studies of space weathering. The SARA instrument consists of neutral atom sensor CENA (Chandrayaan-1 Energetic Neutrals Analyzer), solar wind monitor SWIM and DPU (Data Processing Unit). CENA and SWIM interface with DPU, which in turn interfaces with the spacecraft. The masses of CENA, SWIM and DPU are 2 kg, 0.5 kg and 2 kg respectively, totaling the SARA mass as 4.5 kg.



C1XS

The primary goal of the Chandrayaan-1 X-ray Spectrometer (C1XS) instrument from ESA is to carry out high quality X-ray spectroscopic mapping of the Moon, in order to constrain solutions to key questions on the origin and evolution of the Moon. C1XS uses X-ray fluorescence spectrometry (1.0-10 keV) to measure the elemental abundance, and map the distribution, of the three main rock forming elements: Mg, Al and Si. During periods of enhanced solar activity (solar flares) events, it may be possible to determine the abundance of minor elements such as Ca, Ti and Fe on the surface of the Moon. The instrument utilises technologically innovative Swept Charge Device (SCD) X-ray sensors, which are mounted behind low profile gold/copper collimators and aluminium/polycarbonate thin film filters. The system has the virtue of providing superior X-ray detection, spectroscopic and spatial measurement capabilities, while also operating at near room temperature. A deployable proton shield protects the SCDs during passages through the Earth's radiation belts, and from major particle events in the lunar orbit. In order to record the incident solar X-ray flux at the Moon, which is needed to derive absolute lunar elemental surface abundances, C1XS also includes an X-ray Solar Monitor.

Miniature Synthetic Aperture Radar (MiniSAR) is from Applied Physics Laboratory, Johns Hopkins University and Naval Air Warfare Centre, USA through NASA. The scientific objective of Mini-SAR is to detect water ice in the permanently shadowed regions on the Lunar poles, upto a depth of a few meters. Although returned lunar samples show the Moon to be extremely dry, recent research suggests that water-ice may exist in the polar regions. Because its axis of rotation is perpendicular to the ecliptic plane, the poles of the Moon contain areas that never receive light and are permanently dark. This results in the creation of "cold traps", zones that are never illuminated by the sun, may be as cold as 50–70 K. Cometary debris and meteorites containing water-bearing minerals constantly bombard the Moon. Most of this water is lost to space, but, if a water molecule finds its way into a cold trap, it remains there forever – no physical process is known that can remove it. Over geological time, significant quantities of water could accumulate. The synthetic aperture radar system works at a frequency 2.38 GHz, with a resolution of 75 m per pixel from 100 km orbit and its mass is 8.77 kg.

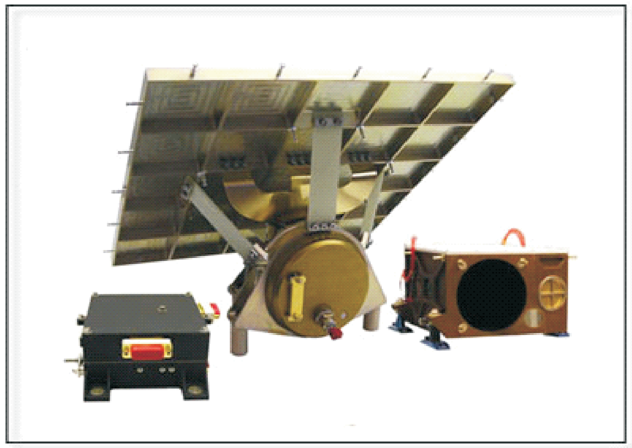


Mini-SAR

The High-Energy X-ray spectrometer (HEX), developed by PRL covers the hard X-ray region from 30 keV to 270 keV. This is the first experiment to carry out spectral studies of planetary surface at hard X-ray energies using good energy resolution detectors. The High Energy X-ray experiment is designed primarily to study the emission of low energy (30-270 keV) natural gamma-rays from the lunar surface due to 238U and 232Th and their decay chain nuclides. The geometric detector area of 144 cm2 is realized by nine Cadmium Zinc Telluride (CZT) arrays, each 4 cm x 4 cm (5 mm thick), composed of 256 (16x16) pixels (size: 2.5 mm x 2.5 mm). Each CZT array is readout using two closely mounted Application Specific Integrated Circuits (ASICs), which provides self-triggering capability. The detector is biased at the cathode with –550 V and the electronic charge signals are collected at the anode. A Cesium Iodide (CsI (Tl)) scintillator crystal coupled to photomultiplier tubes (PMT), is used as the anticoincidence system (ACS) for reducing the detector background. A specially designed collimator provides a field of view (FOV) of 40 km X 40 km at the lunar surface from a 100 km orbit. The spatial resolution of HEX is 40 km and the mass is 14.4 kg.

HEX

Near Infra Red spectrometer (SIR-2) is from Max-Planck Institute, Germany and ESA and this instrument addresses the surface-related aspects of lunar science .The determination of the chemical composition of a planet's crust and mantle is one of the important goals of planetary research. Diagnostic absorption bands of various minerals and ices, which are expected to be found on the surfaces of planetary bodies, are located in the near-IR range, thus making near-infrared measurements of rocks, particularly, suitable for identifying minerals. SIR-2 is a grating NIR point spectrometer working in the 0.93-2.4 microns wavelength range with 6 nm spectral resolution. It collects the Sun's light reflected by the Moon with the help of a main and a secondary mirror. This light is fed through an optical fiber to the instrument's sensor head, where it is reflected off through a dispersion grating. The dispersed light reaches a detector, which consists of a row of photosensitive pixels that measure the intensity as a function of wavelength and produces an electronic signal, which is read out and processed by the experiment's electronics. The mass of the instrument is 3.3 kg and the instrument unit dimension is 260 mm x 171 mm x 143 mm.



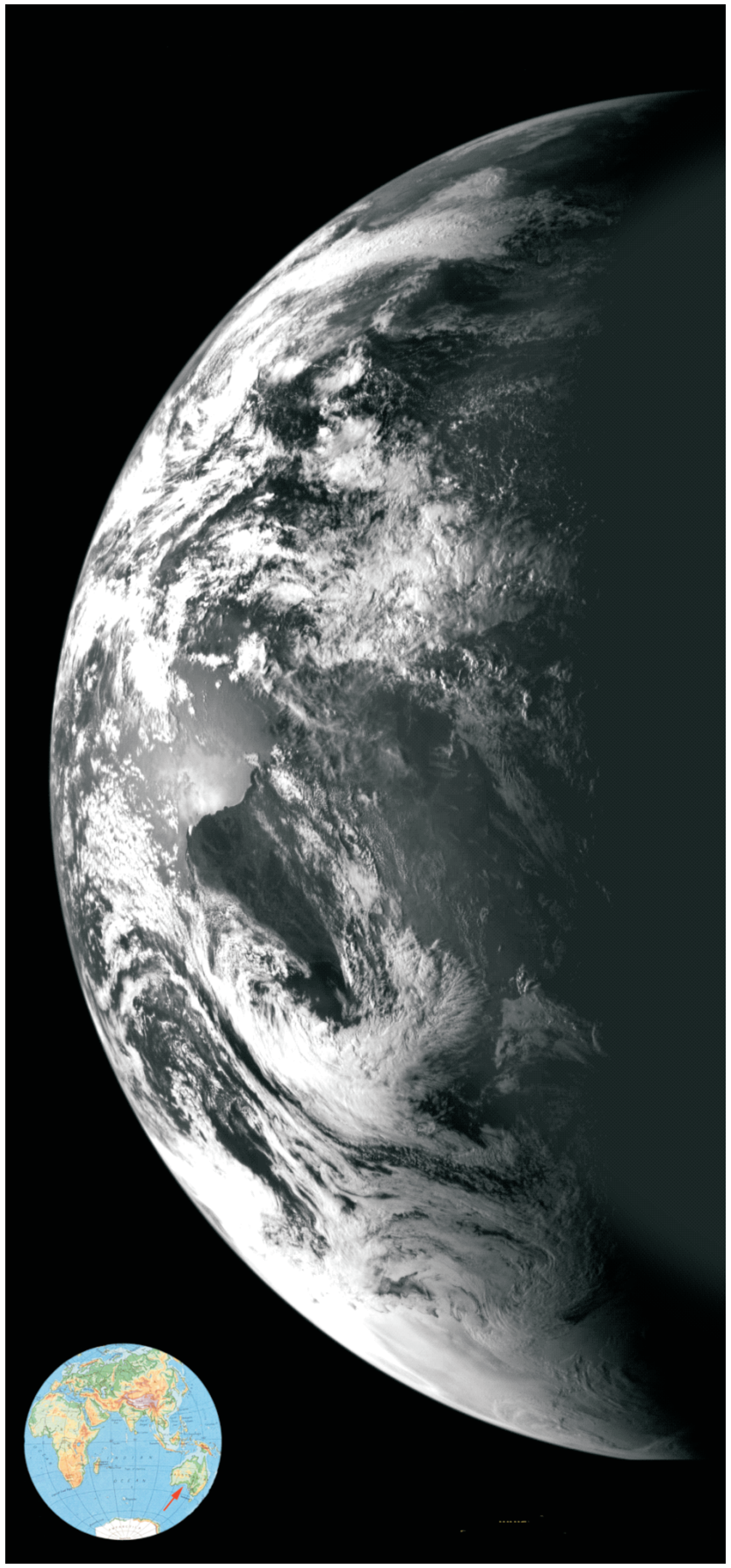
SIR-2

Earth views of Chandrayaan-1 TMC

This Section highlights the Earth views from Chandryaan-1 TMC.

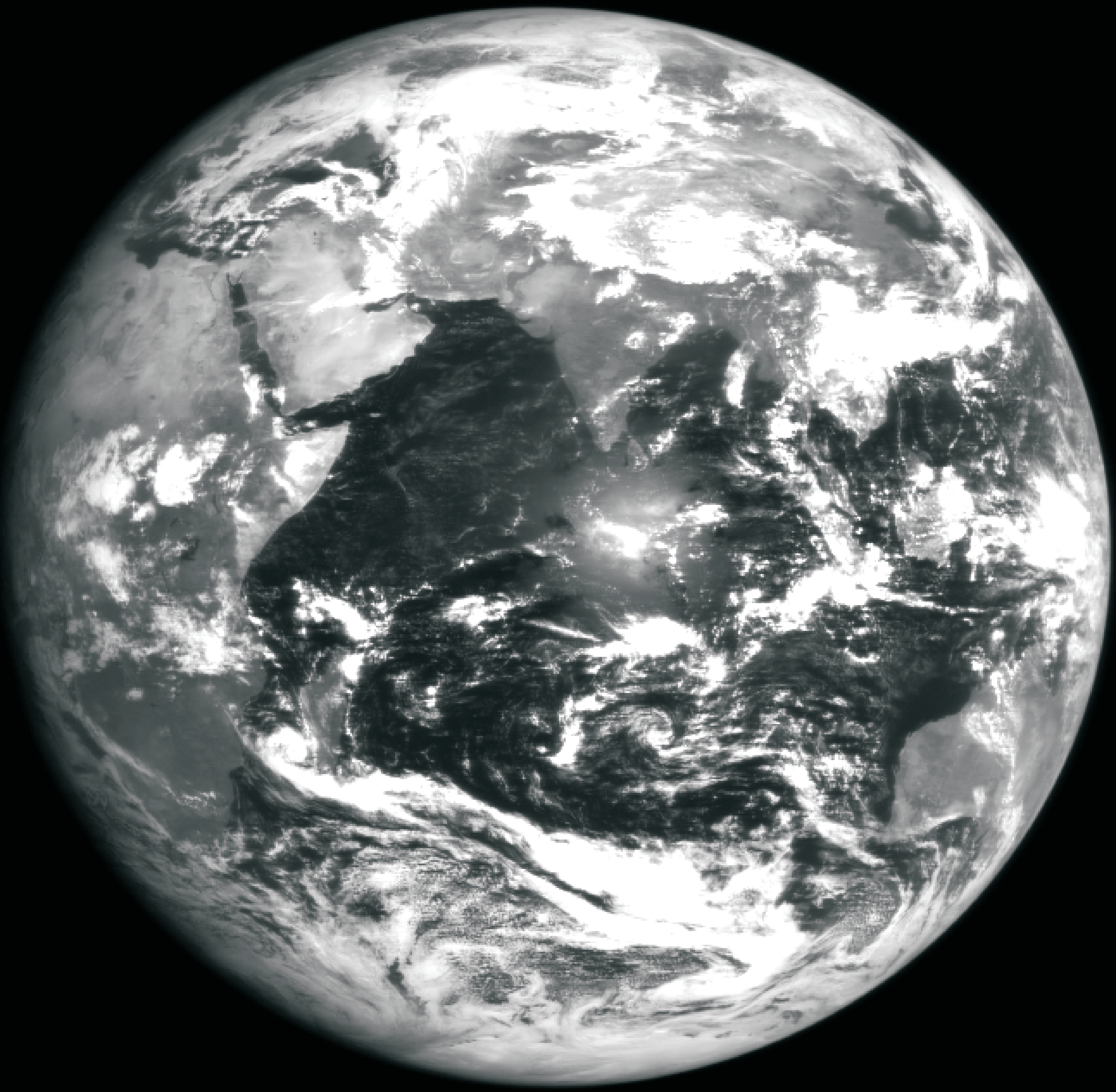
Chandrayaan - 1 TMC Images enroute the moon

the moon as viewed by Chandrayaan-1 on 04-Nov-2008
from a distance ~ 311200 km



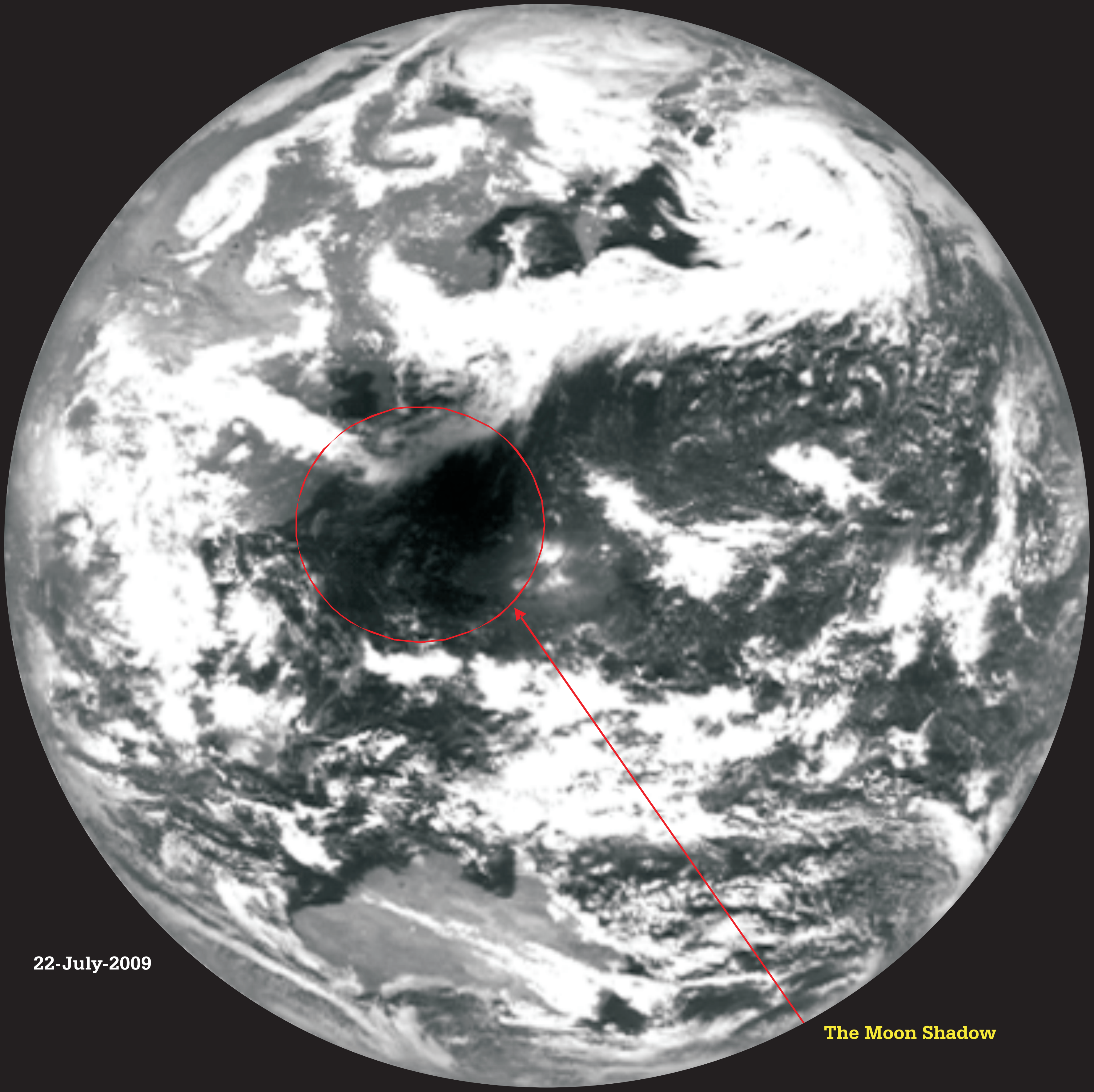
Earth as viewed by Chandrayaan-1 On 29-Oct-2008
from a distance ~ 70000 km

India as viewed by Chandrayaan-1



25-March-2009

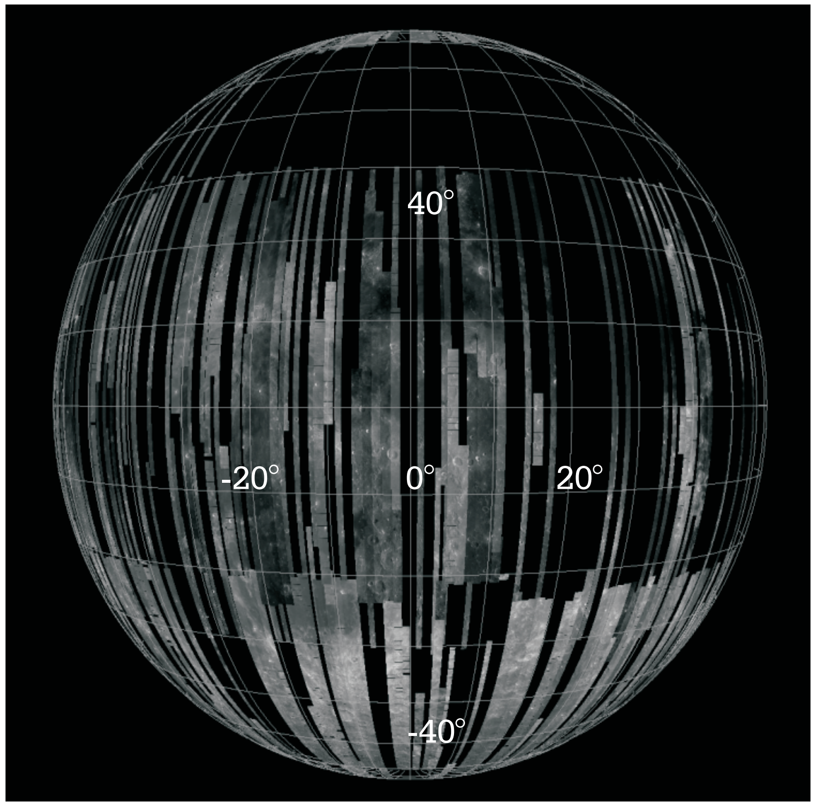
Local Solar Eclipse as viewed by Chandrayaan-1 TMC



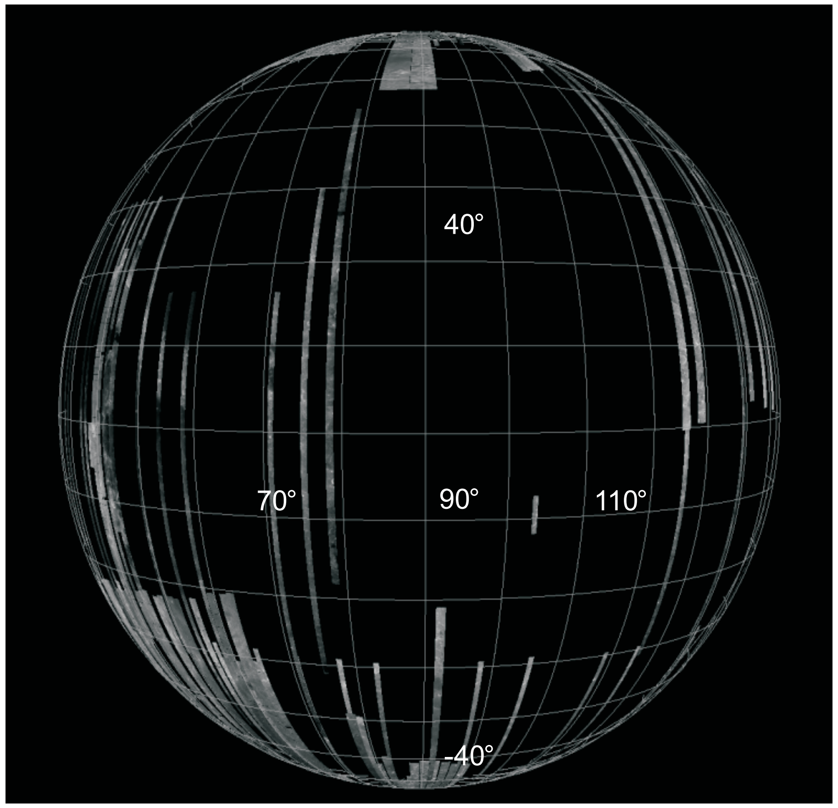
Earth rise over the moon - Viewed by Chandrayaan- 1 TMC on 22.07.2009

Image of Earth from the Moon acquired by TMC. The data were acquired on the 22nd of July 2009 during a local solar eclipse.

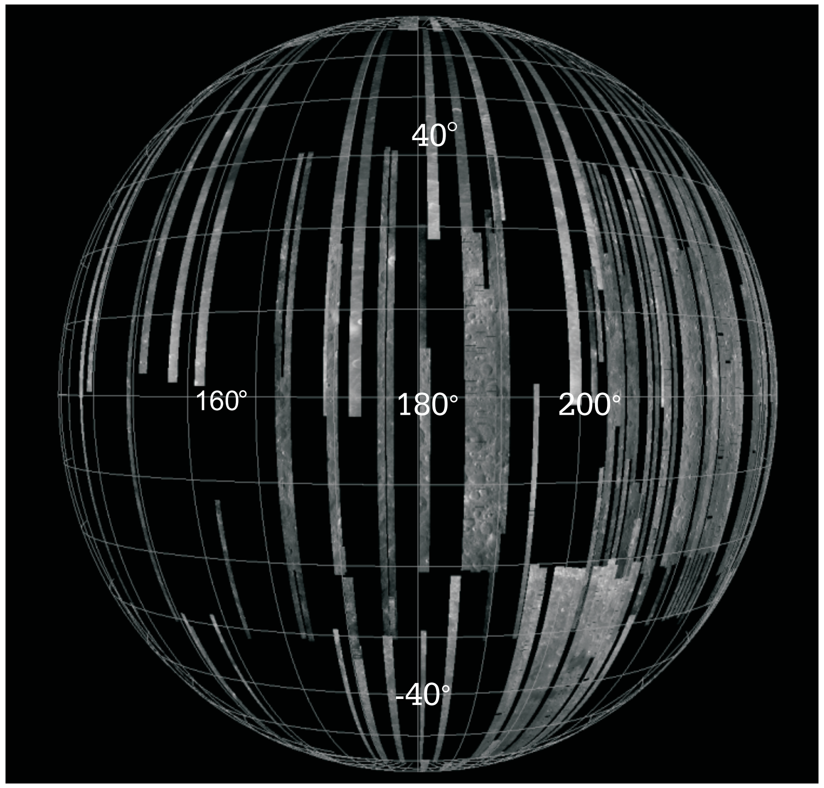
TMC NADIR COVERAGE



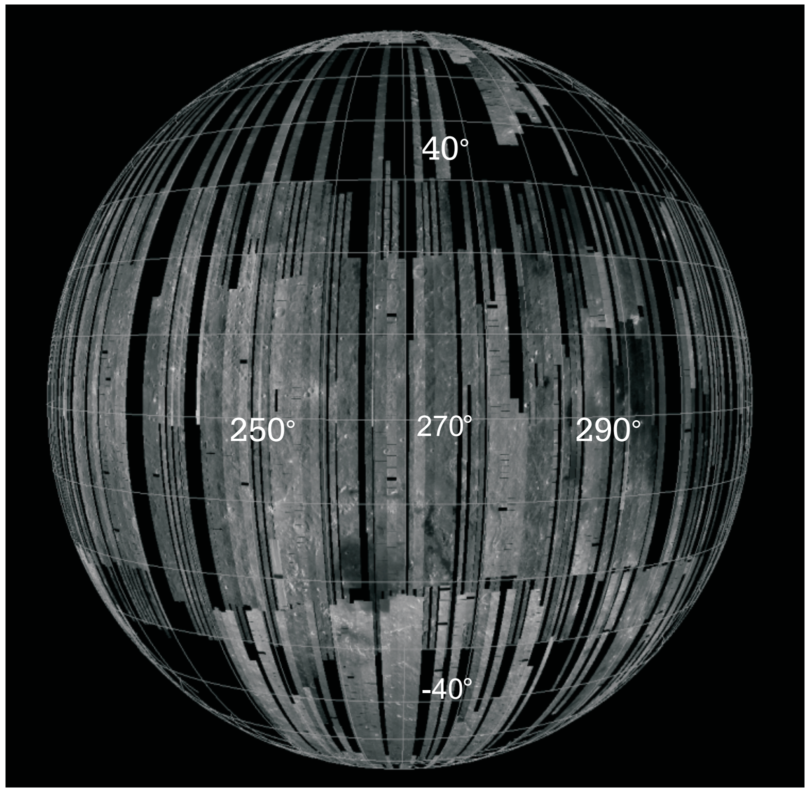
TMC NEAR SIDE 0°



TMC 90°

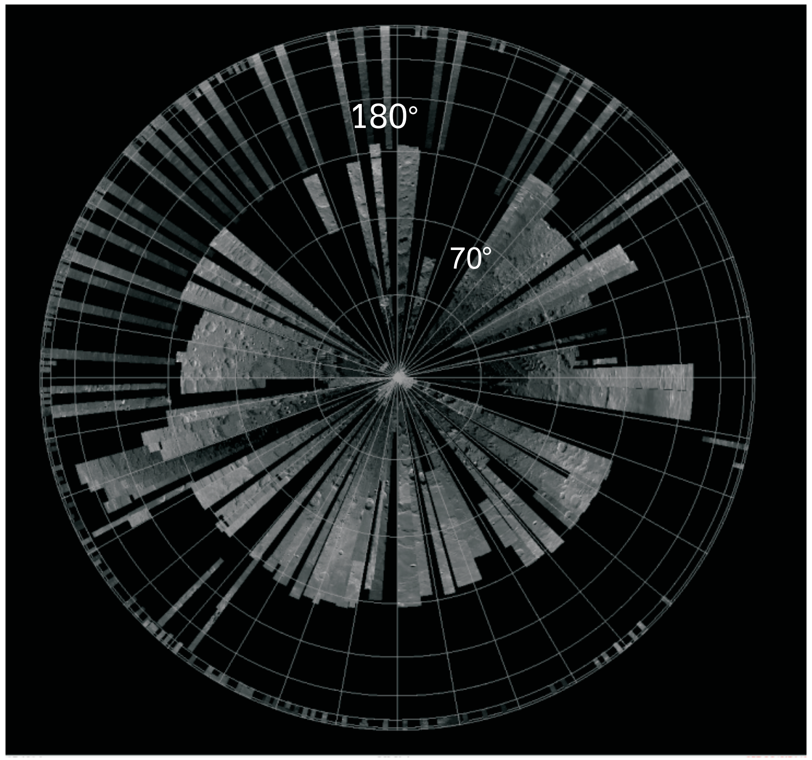


TMC FAR SIDE 180°

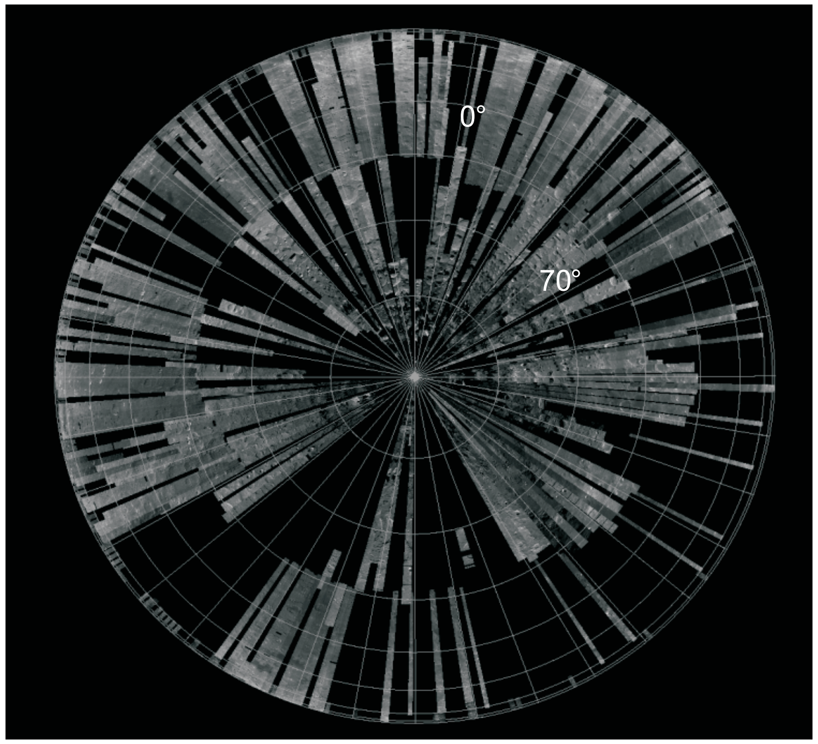


TMC 270°

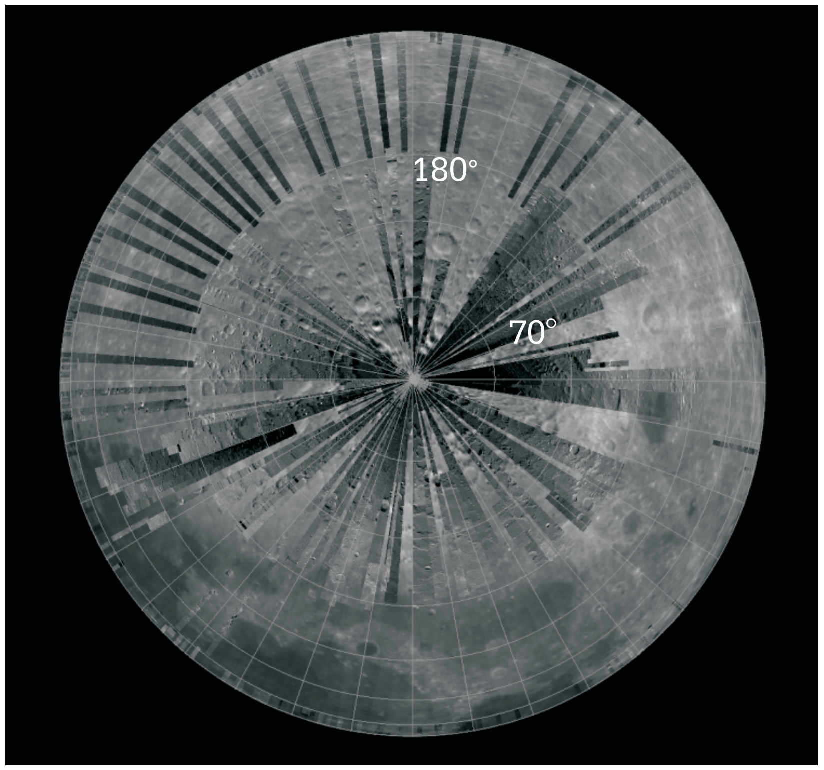
TMC POLAR COVERAGE



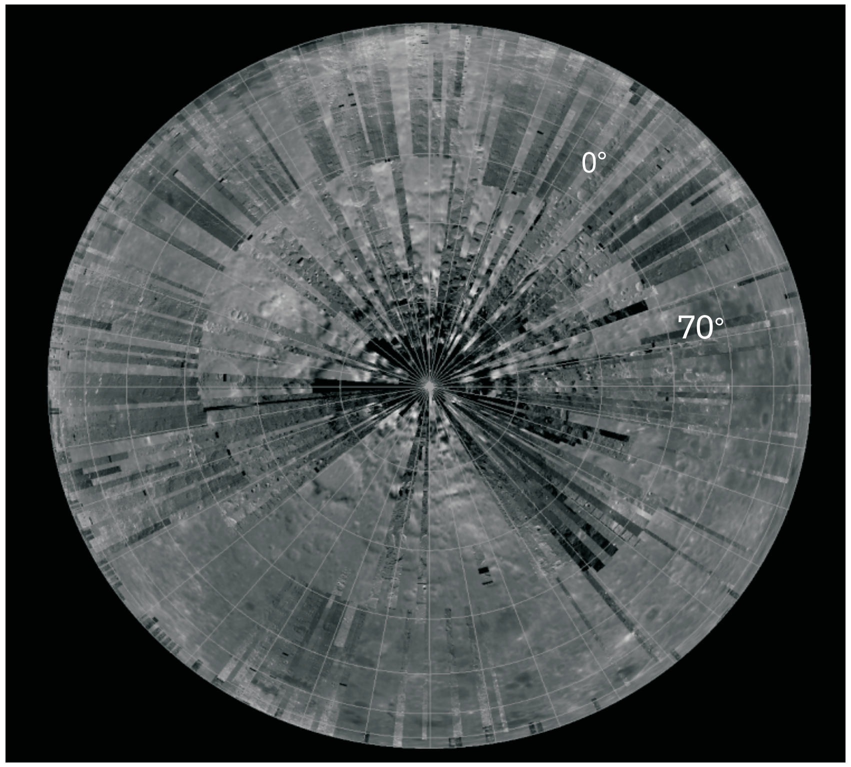
NORTH POLE



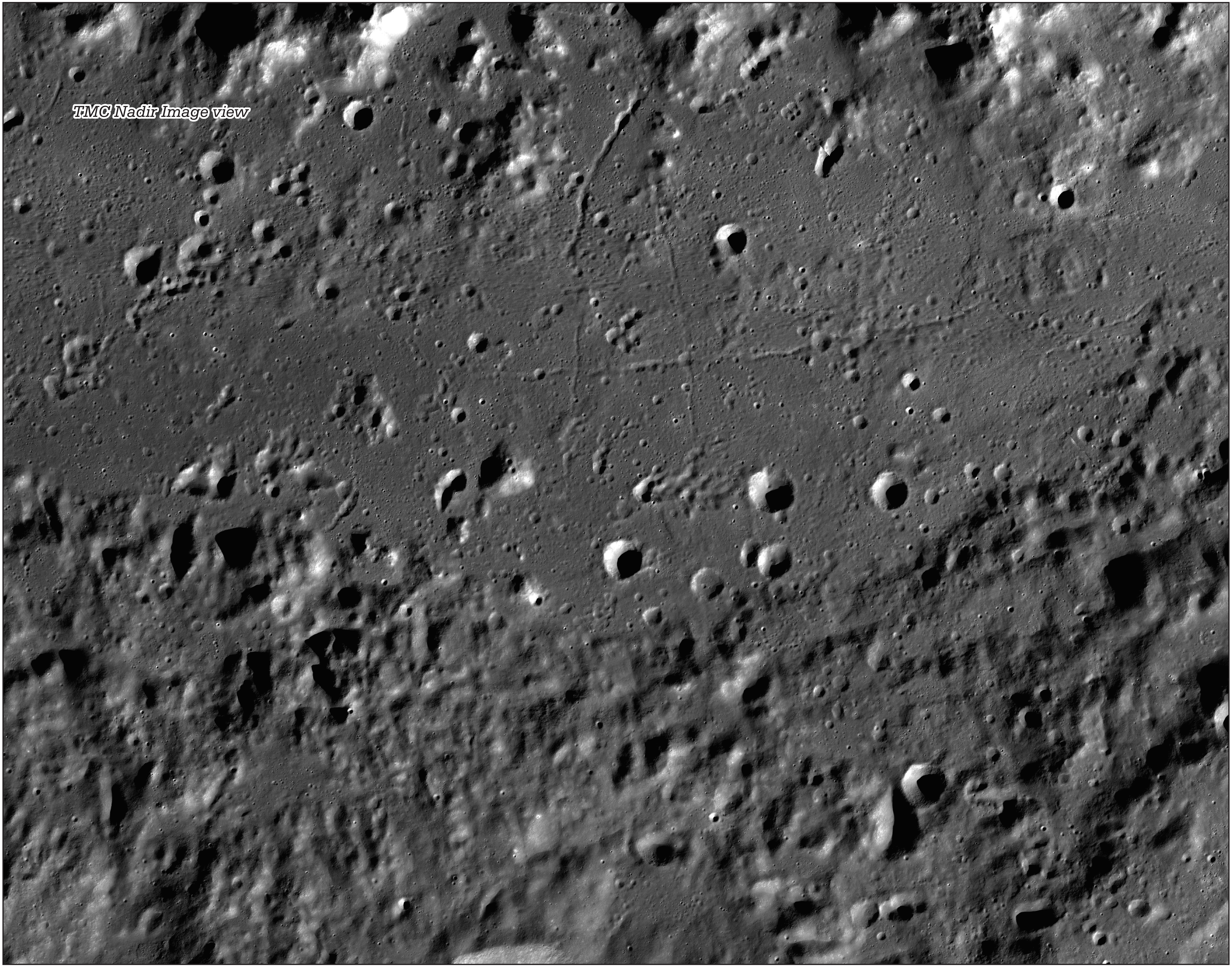
SOUTH POLE



NORTH POLE COVERAGE OVER CLEMENTINE BACK GROUND



SOUTH POLE COVERAGE OVER CLEMENTINE BACK GROUND


TMC Nadir Image view

Morphological Features on the moon surface

The surface of the Moon appears distinctly different from that of the Earth which is dominated by craters, rilles, wrinkle-ridges, lava flows, material ejected from the craters, volcanic cones & hills / mountains. The study of all these features help us understand the chronology of various processes that enacted on the lunar surface.

A wrinkle ridge is a type of feature commonly found on lunar maria. These features are low, crenulated ridges formed on the mare surface. Wrinkle ridges are tectonic features created when the basaltic lava first cooled and contracted. They frequently outline ring structures buried within the mare; follow circular patterns outlining the mare, or intersect protruding peaks. They are sometimes called veins due to their resemblance to the veins that protrude from beneath the skin. These are found near craters

In this section, conical hills/ pyroclastic cones, secondary craters, lava flows , escarpments etc. are discussed. Conical hills/ Pyroclastic cones represent the ejecta projectiles thrown out of the impact crater and deposited around it , forming cones pointing upward. The secondary craters are the craters formed due to the impact of the material thrown out of the main impact crater. They also sometimes indicate the small younger craters within very large old craters. The lava flows represent the impact melts flowing down the slopes of major impact craters. Escarpments may at times represent the boundary of various layers of basaltic lava.

Morphological Features

These features are also found in other planets (Mercury, Venus, Mars, Jupiter, Saturn). The features are more or less alike, but in case of craters in Venus, its different from others.

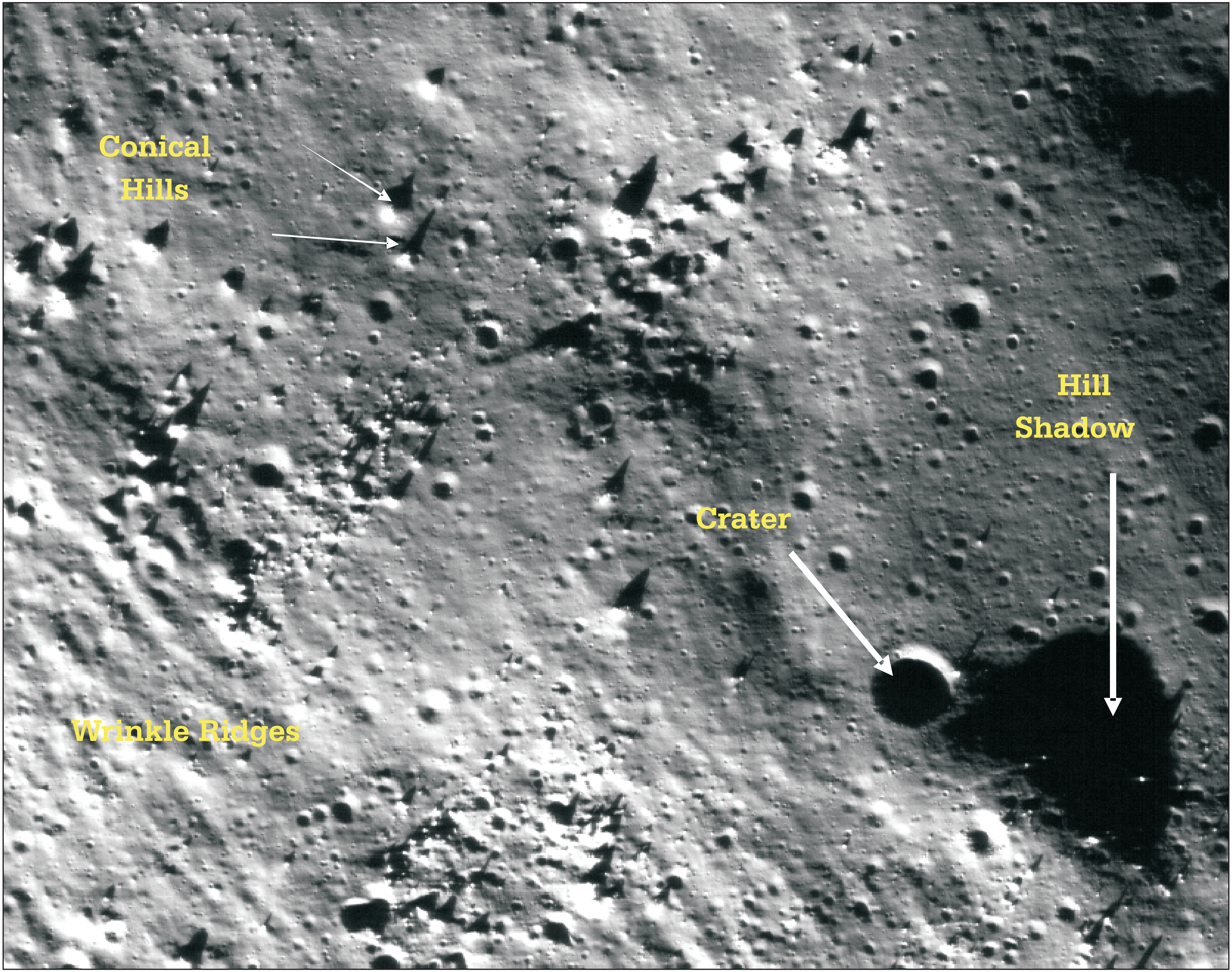
Features	Mercury	Venus	Mars	Jupiter	Saturn
Wrinkle ridges	✓	✓	✓	✓	✓
Lava flows	✓	✓	✓	✓	✓
Volcanic cones	✓	✓	✓	✓	✓

Morphological Features on the Moon

In this figure, conical hills, wrinkle ridges, lava flows, pyroclastic cones are displayed. Conical Hills represent pyroclastic cones formed around major crater from the projectile material thrown out of the large craters. Wrinkle ridges are features created by compressive tectonic forces within the maria. These features are low, sinuous ridges formed on the mare surface that can extend for up to several hundred kilometers. These features represent buckling of the surface and form long ridges across parts of the maria. Some of these ridges may outline buried craters or other features beneath the mare.

Location : Near Side; North Polar Region

Orbit no : 90; Date of Pass: 16-11-2008; Scale- 1:35750;Nadir Image

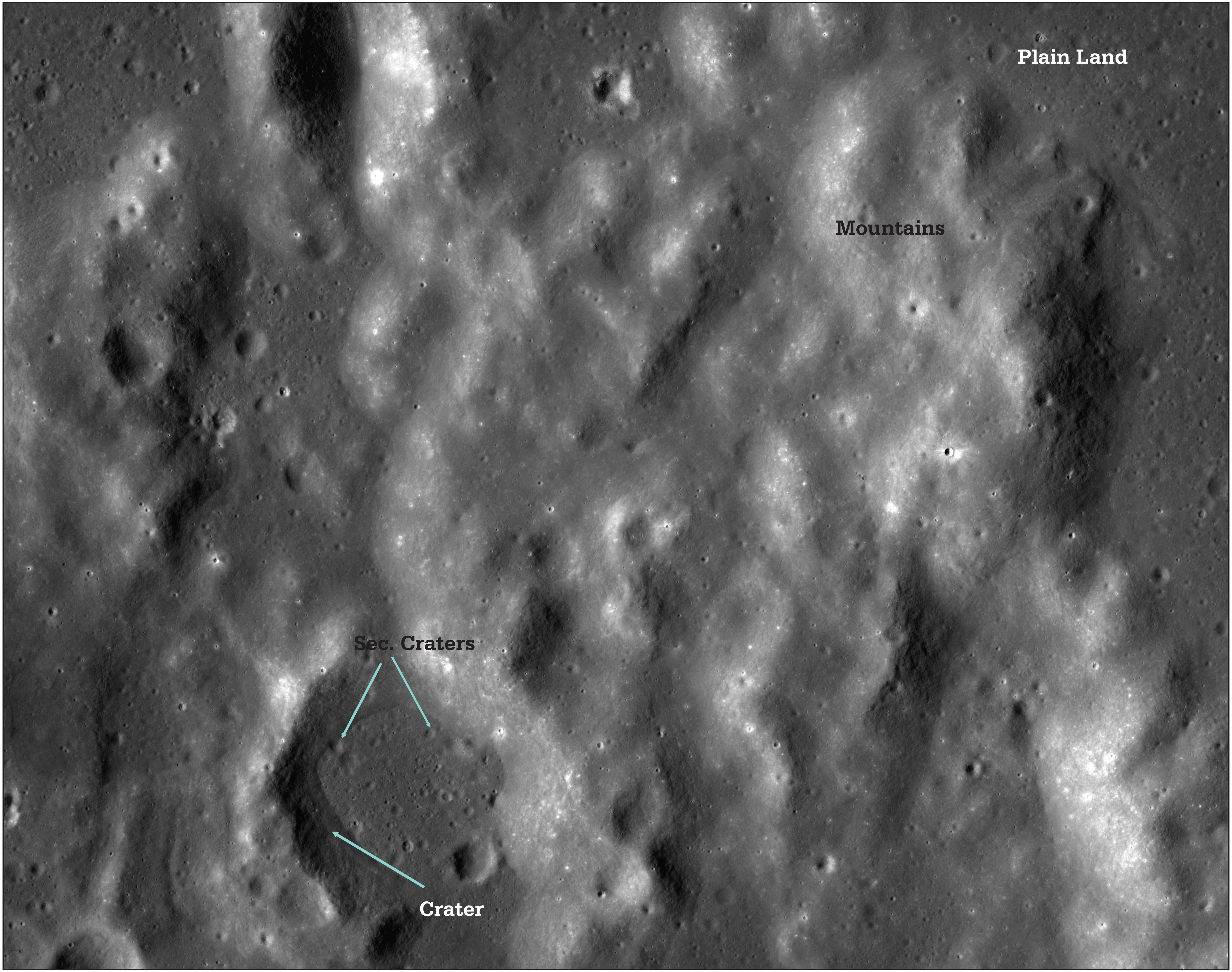

Conical Hills
Hill Shadow
Crater
Wrinkle Ridges

Morphological Features on the Moon

Craters & secondary craters within craters. Mountains represent highlands. Plain land consists of younger craters.
Secondary craters are impact craters formed by the ejecta that was thrown out of a larger crater. They sometimes form radial crater chains.

Location : Montes Area; Near Side; Equatorial Region

Orbit no : 1935; Date of Pass: 17-04-2009; Scale- 1:60000;Nadir Image


Plain Land
Mountains
Sec. Craters
Crater

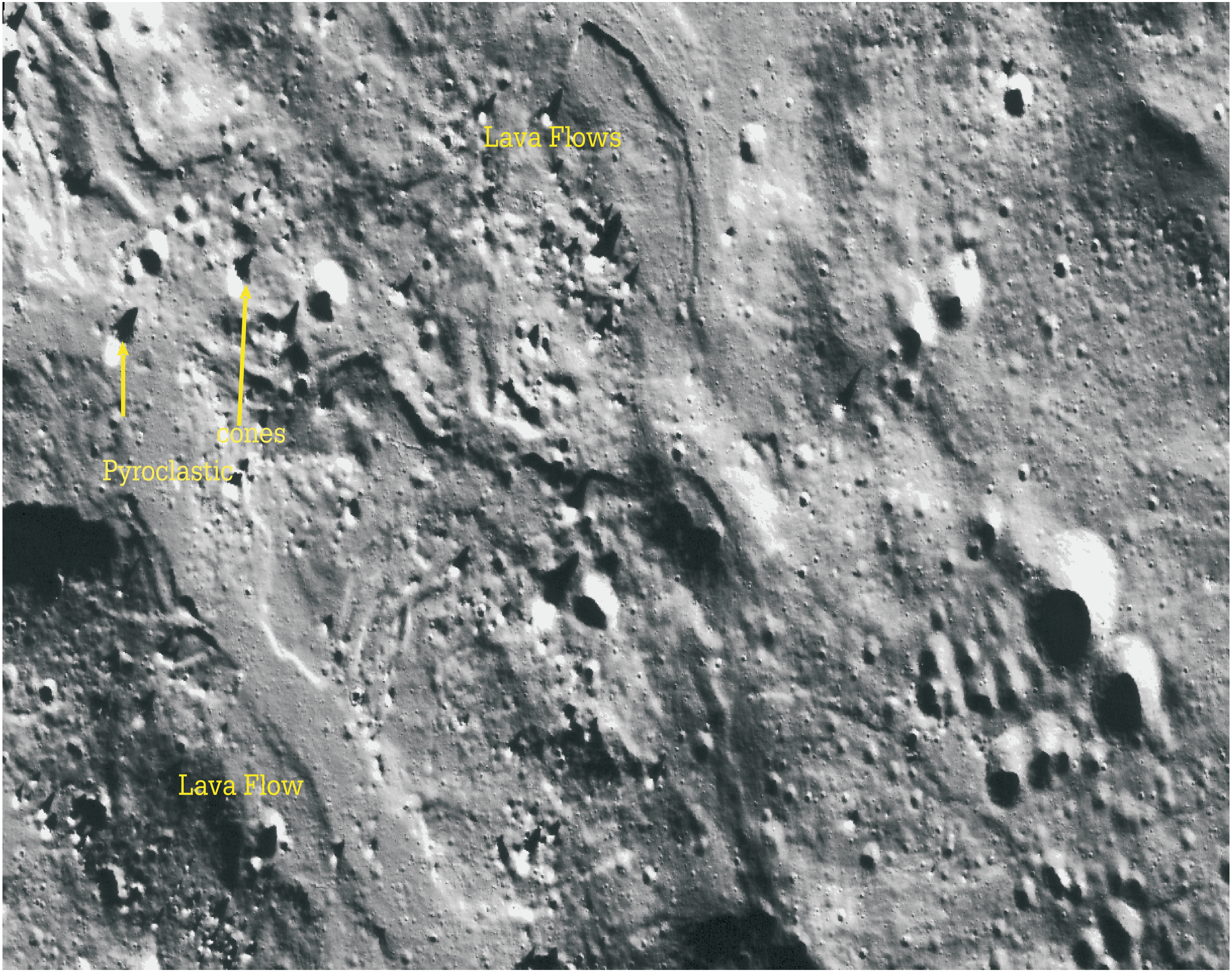
Morphological Features on the Moon

Lava flows represent spill-over of the Magma derived from the carter floor or the impact melt.

The lava flow structures are commonly found in the lunar mare surfaces which are darker in colour. The lava flows forms channelised structural features like rilles etc. Most of the lava flows are basaltic in composition.

Location : Near Side; North Polar Region

Orbit no : 90; Date of Pass : 16-11-2008; Scale- 1:61750;Nadir Image


Lava Flows
cones
Pyroclastic
Lava Flow

Morphological Features on the Moon

This part of lunar surface shows a crater and is floor. The feature on the floor is an example of moltem material effusing out of crater floor which got solidified later. This supports the view of of eruption through the crater floors and this is rare evidence of craters becoming vent for volcanic material to come to surface. This has happened because the bigger crater has been further penetrated by secondary craters allowing the underlying magmatic material to gush out on the surface.

Location : Near Side; South Polar Region

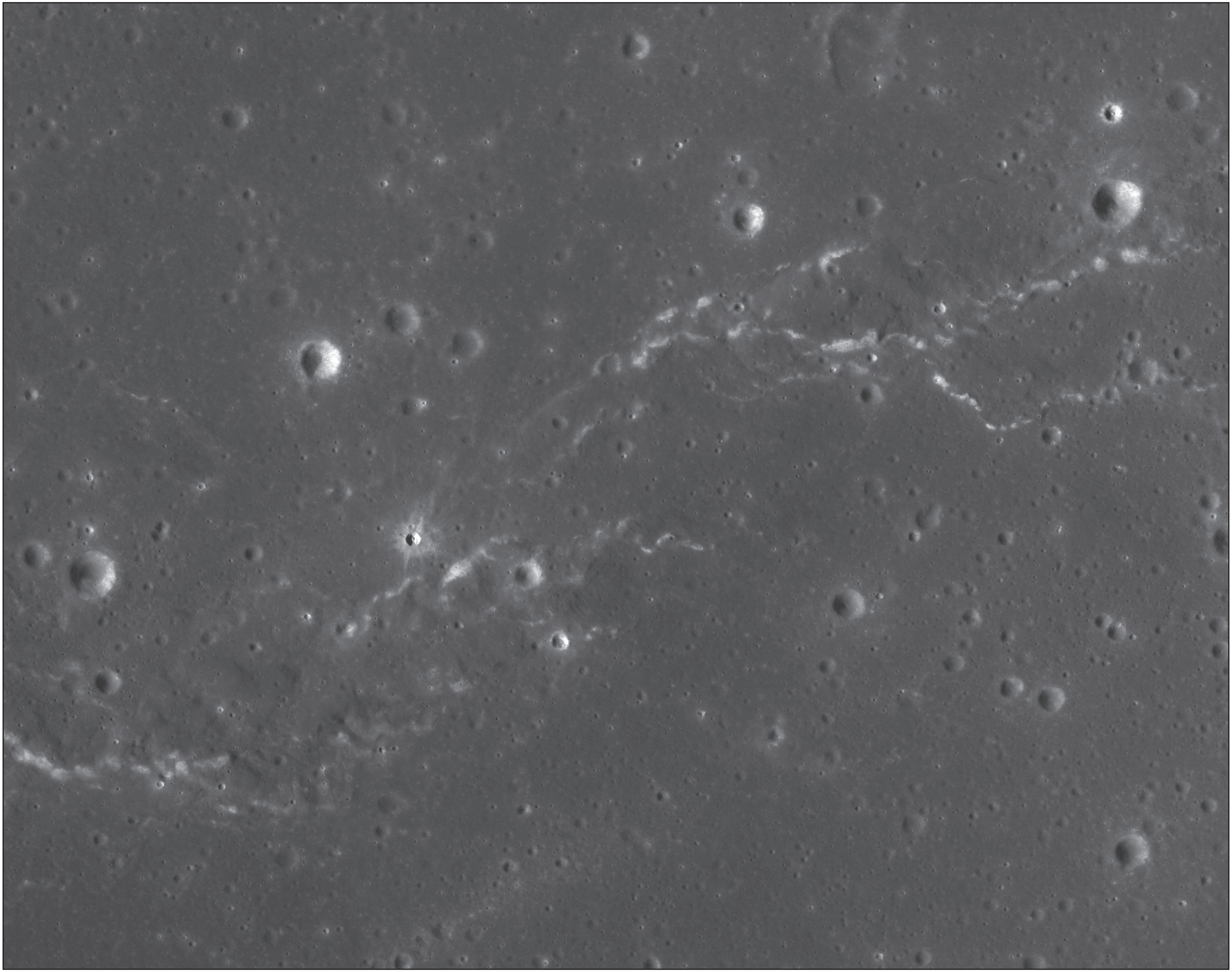
Orbit no : 2877; Date of Pass: 06-07-2009; Scale- 1:205000;Nadir Image

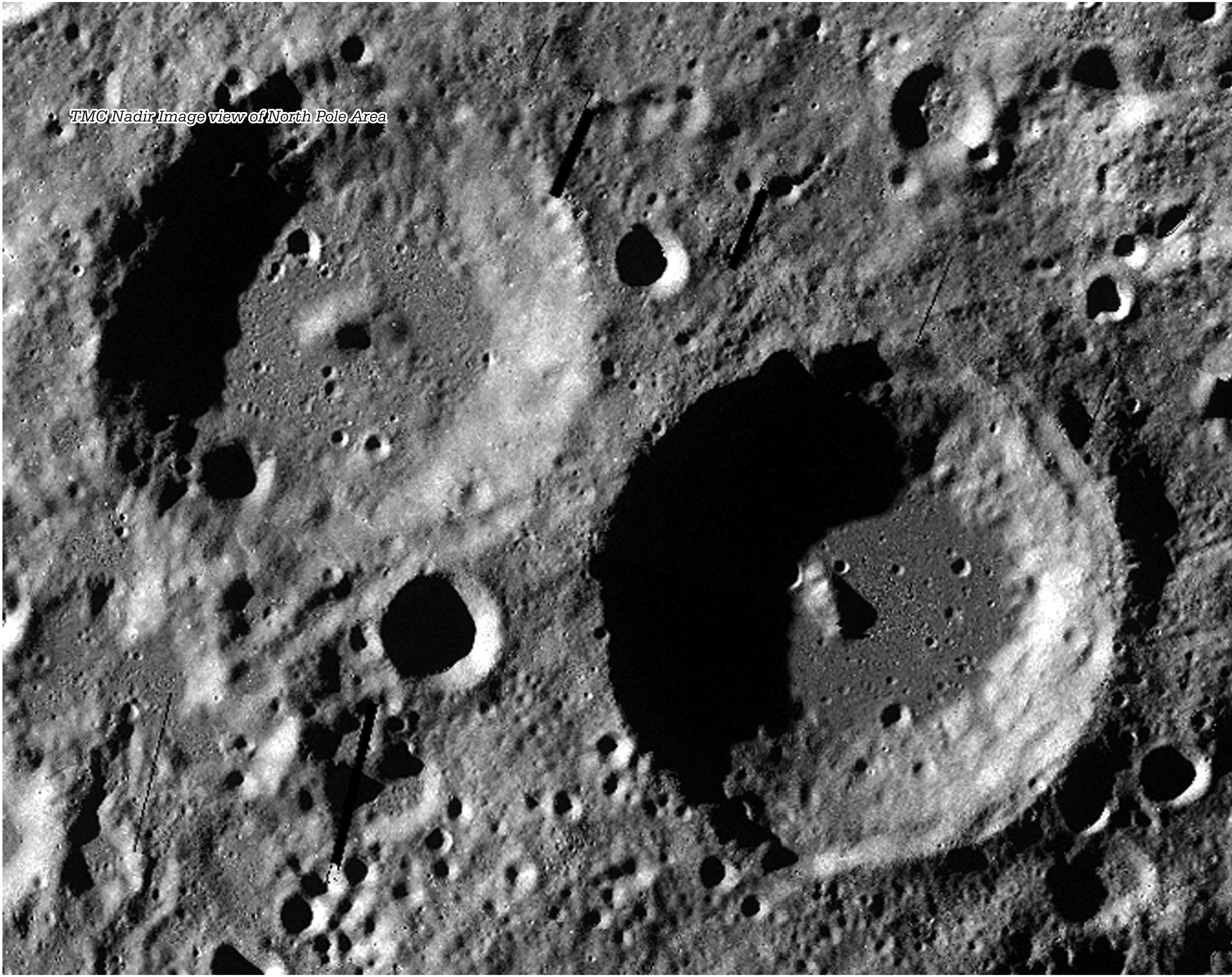
Morphological Features on the Moon : Escarpments

The drainage like features on the lunar surface with a dark tone of background rocks are probably the contacts of different volcanic flows. These are similar to escarpments (walls of a plateau). The thickness of these escarpments is indicative of thickness of volcanic flows. The illumination of these wall like features is similar to the illumination of craterswalls seen around these features. The dark tone of surface indicates high concentration of ferromagnesian minerals of basaltic flows. The craters showing different degree of illumination are indicative of chronological history of different craters.

Location : Near Side; Equatorial Area

Orbit no :1973; Date of Pass: 20-04-2009; Scale – 1:155000;Nadir Image





TMC Nadir Image view of North Pole Area

Craters types & Morphology

Craters are depressions on the lunar surface, created by the impact of falling objects. The rate & size of cratering of Lunar surface has reduced drastically over period of time. Impacts at high speeds produce shock waves in solid materials, and both impactor and the material impacted are rapidly compressed to high density. Following initial compression, the high-density, over-compressed region rapidly depressurizes, exploding violently, to set in train the sequence of events that produces the impact crater.

It is convenient to divide the impact process conceptually into three distinct stages: (1) initial contact and compression, (2) excavation, (3) modification and collapse. In practice, there is overlap between the three processes, for example, while the excavation of the crater continuing in some regions, modification and collapse is already underway in others.

The study of size, age & type of craters help in re-constructing the geological history of the Moon. The crater study can be grouped into three categories:

- Crater Morphology
- Crater Types
- Crater Chronology

.

Craters are also found on Mercury, Venus, Mars, Jupiter, Saturn. But in Venus, the craters are different from others and as there are no evidences of simple & ray craters till now, owing to the thicker atmosphere as compared to other planets which have thinner or no atmosphere, thus permitting the smaller extra-planetary bodies to make contact with their surface

Features	Mercury	Venus	Mars	Jupiter	Saturn
Ray craters	✓	No evidence yet	✓	✓	✓
Simple craters	✓	No simple craters	✓	✓	✓
Complex craters	✓	✓	✓	✓	✓

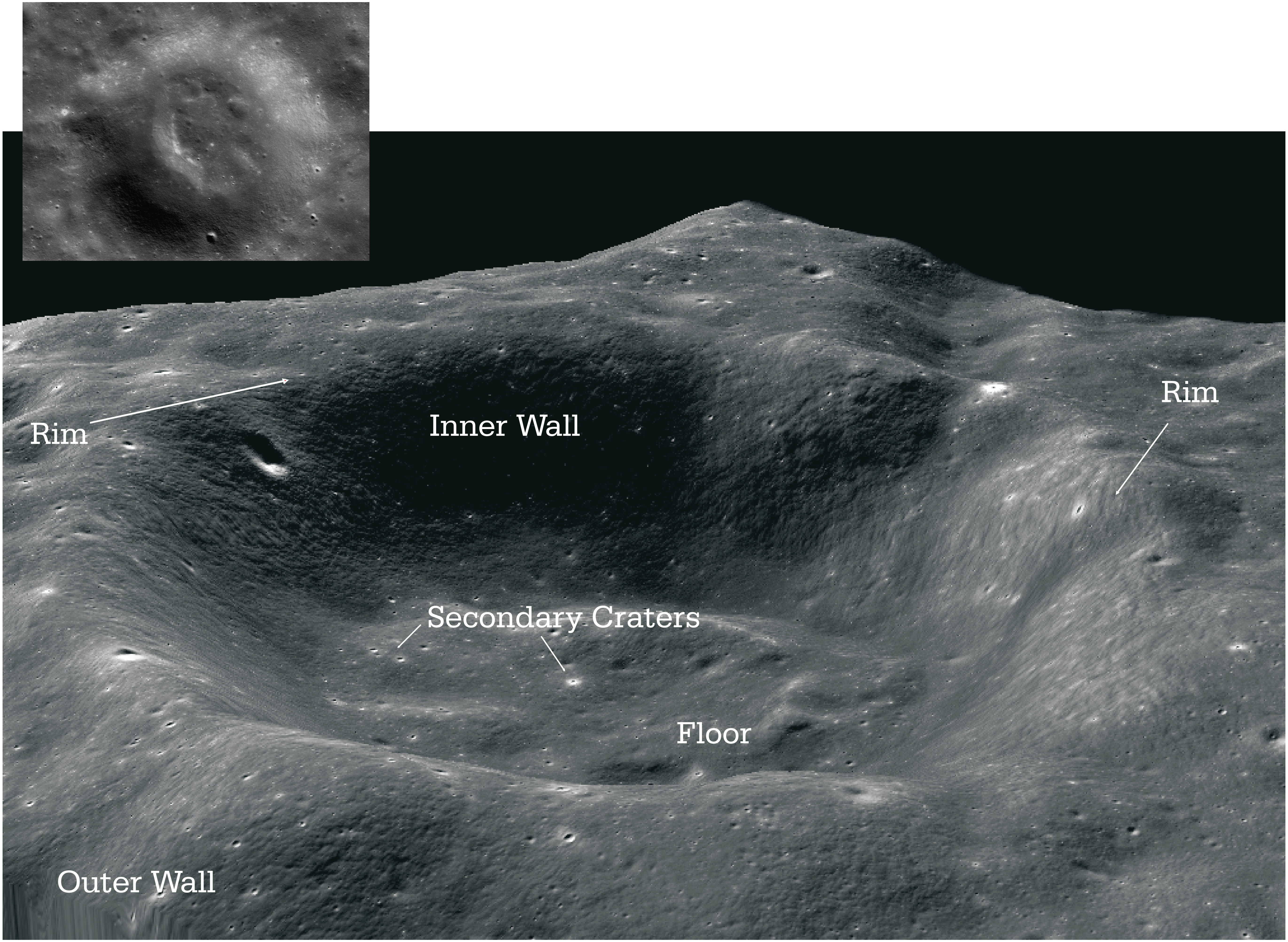
In this section, simple craters, complex craters, ray craters, over stepping craters, craters within craters, linear array of craters, and crater morphology (inner wall, outer wall, floor, rim, slump wall material, central peaks, scalloped rim structure etc.) are displayed. These craters vary in size, age & composition.

Crater Morphology

Three dimensional lay out of atypical crater showing its various features like Rim, Inner Wall, Outer Wall, Floor and Secondary small craters within the floor.Coulomb crater, a diameter of 89 km,lies on the far side of the Moon. It is located to the west-southwest of the large crater Poczobutt, and northeast of Sarton. The rim of this crater is mildly eroded, but still retains a well-defined edge and displays some old terracing on the wide inner walls. The exterior of the crater also retains something of an outer rampart, extending for about a third of crater diameter. The inner walls of the crater have only a few small impacts along the sides.

Location :Coulomb Crater Area; Far Side; Equatorial Region

Orbit no : 181; Date of Pass : : 24-11-2008; Image Drape View;Nadir Image

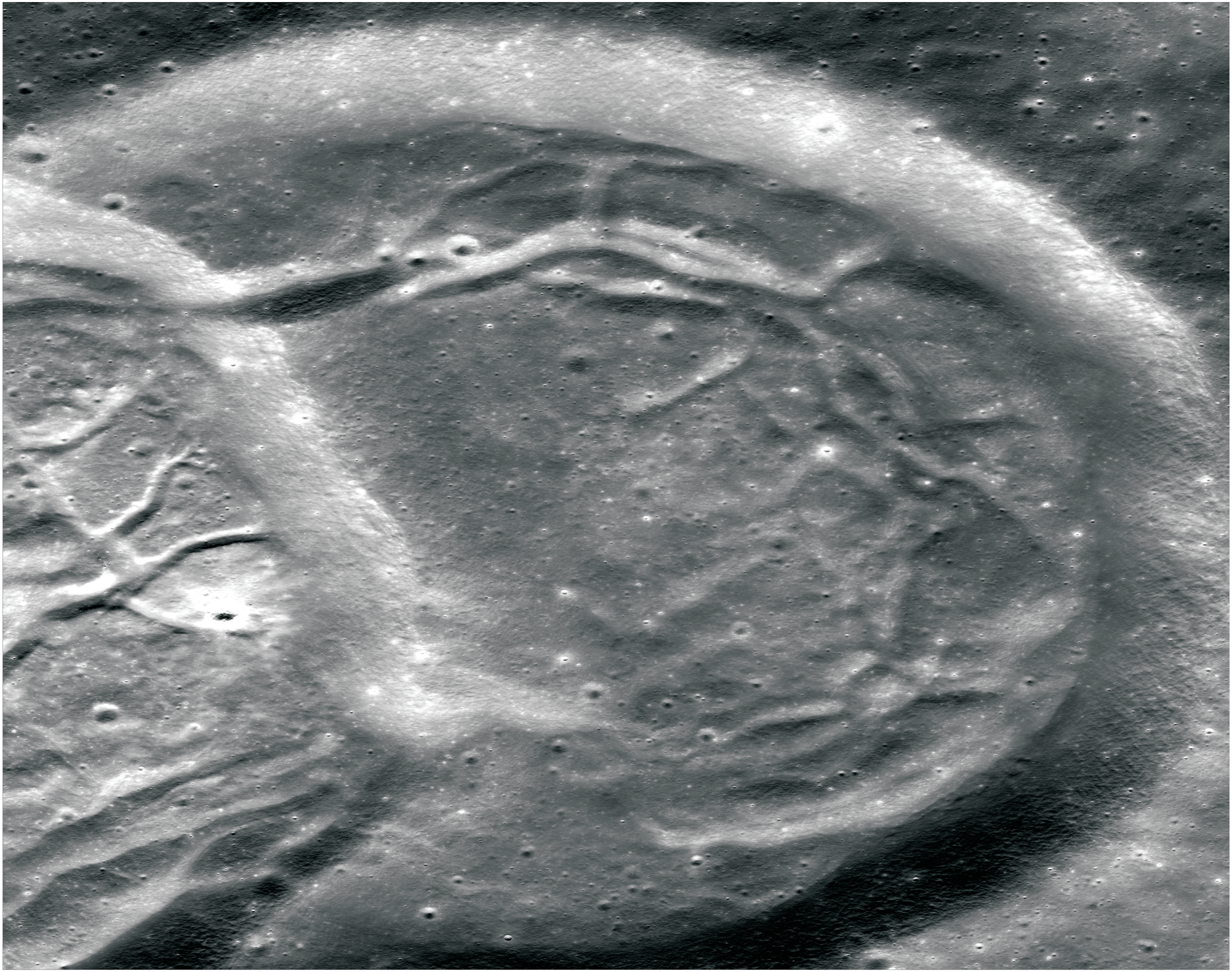

Rim
Inner Wall
Rim
Secondary Craters
Floor
Outer Wall

Crater Morphology : Over-stepping Craters

Sarton crater, a diameter of 69 km, lies on the far side. It is located to the southwest of the crater Coulomb. The crater on the left hand side is superimposed over the crater in right hand side, which implies that the crater on Left hand side is younger than right hand side.
A network of rilles is seen around the floor of the craters. Such a feature of rilles is most probably an indication of impact induced or volcanic processes.

Location :Sarton Crater Area; Far Side; North Polar Region

Orbit no : 523; Date of Pass : 22-12-2008; Scale – 1:295000;Nadir Image

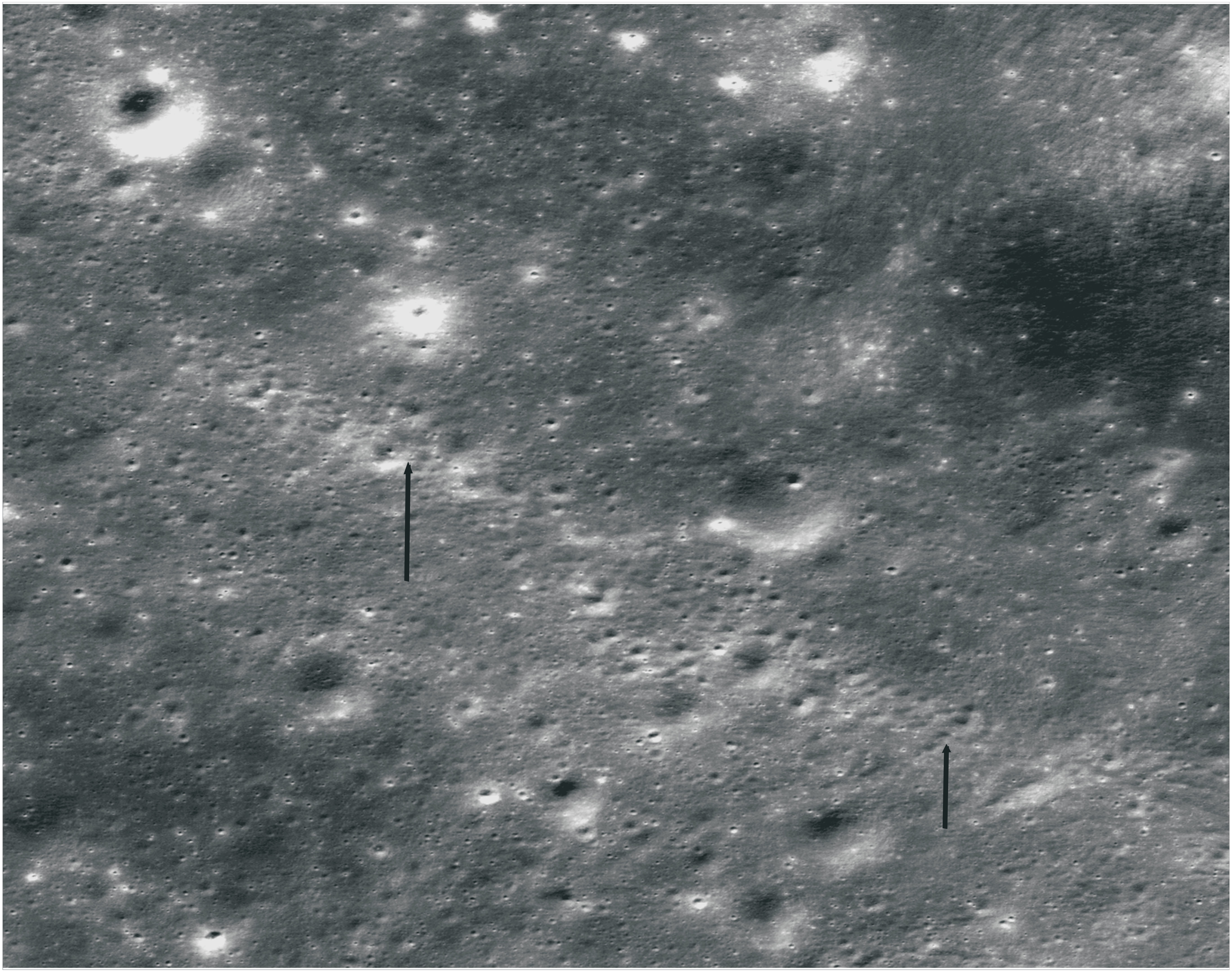


Crater Morphology : Linear Array of Craters

A crater chain is a line of craters along the surface of an astronomical body. The descriptor term for crater chains is catena (plural catenae). Crater chains seen on the Moon often radiate from larger craters, and are thought to be either caused by secondary impacts of the larger crater's ejecta or by volcanic venting activity along a rift.

Location : Vander Wall Area; Far Side; South Polar Region

Orbit no : 295; Date of Pass : 03-12-2008; Scale – 1:64000;Nadir Image

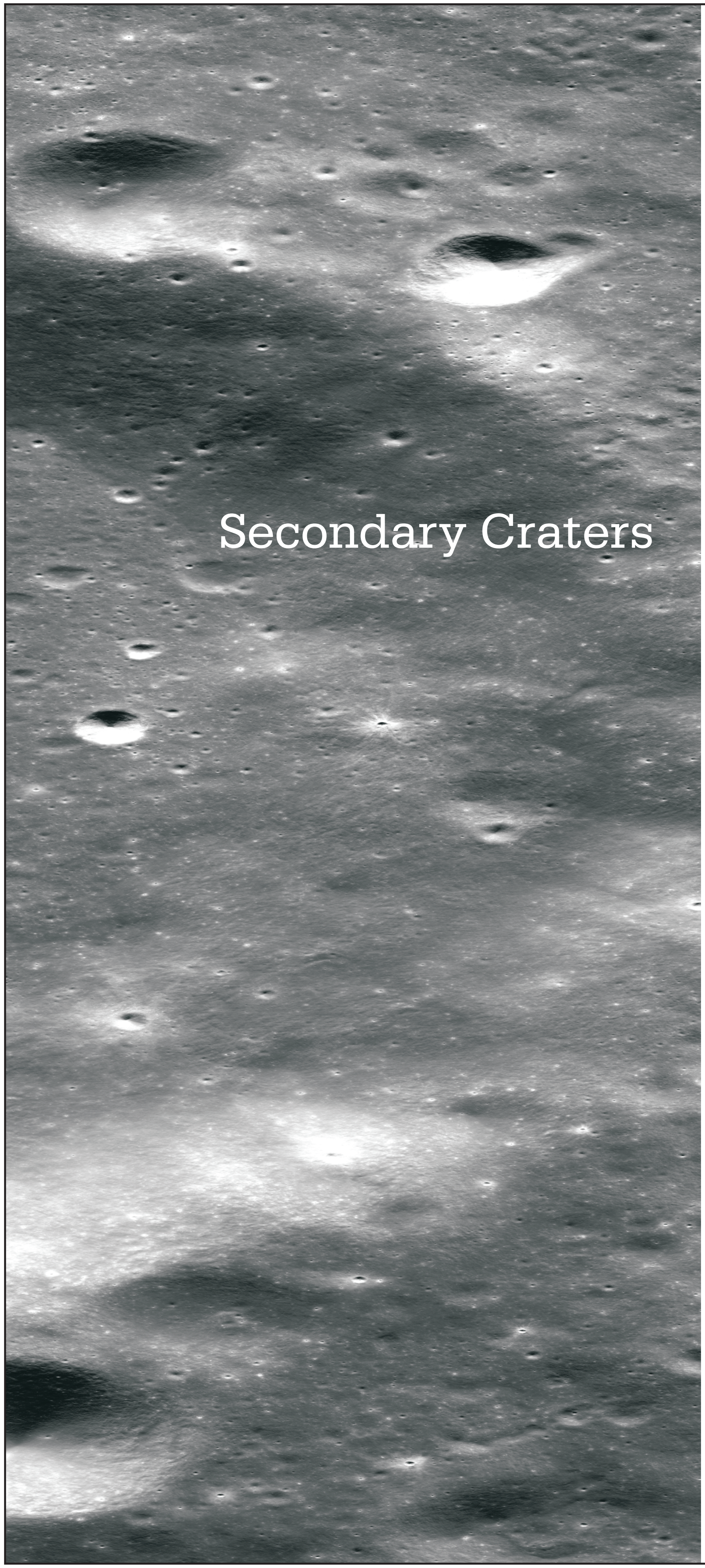


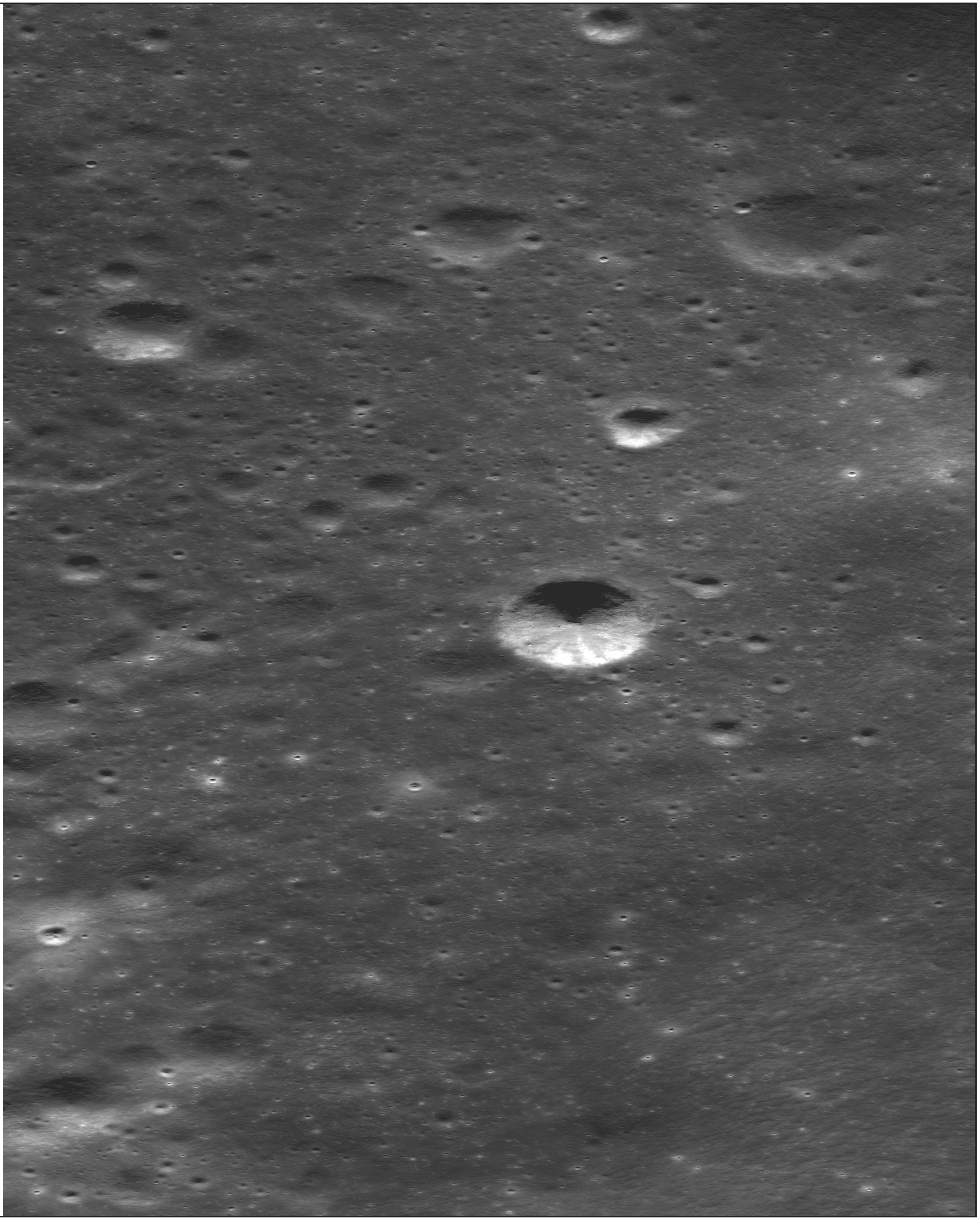
Crater Morphology : Crater within Craters

Rost crater, a diameter of 49km, is in the southwestern part of the Moon and to the southeast of the elongated formation Schiller. The craters within craters usually implies craters within the broad floor of the bigger craters. The craters within are younger in event and these craters are significant in studying the floor of craters.

Location : Rost Crater Area; Near Side; South polar Region

Orbit no : 440; Date of Pass : 15-12-2008; Scale – 1:199500;Nadir Image


Secondary Craters



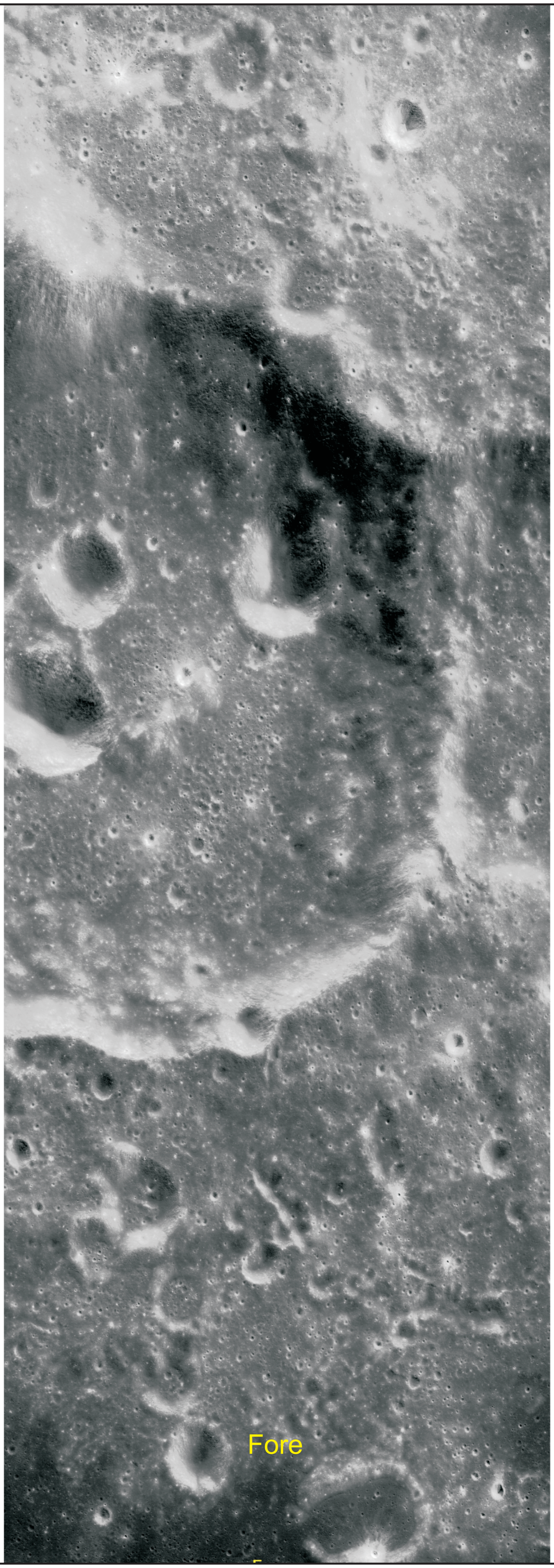
Crater Morphology : Crater within craters

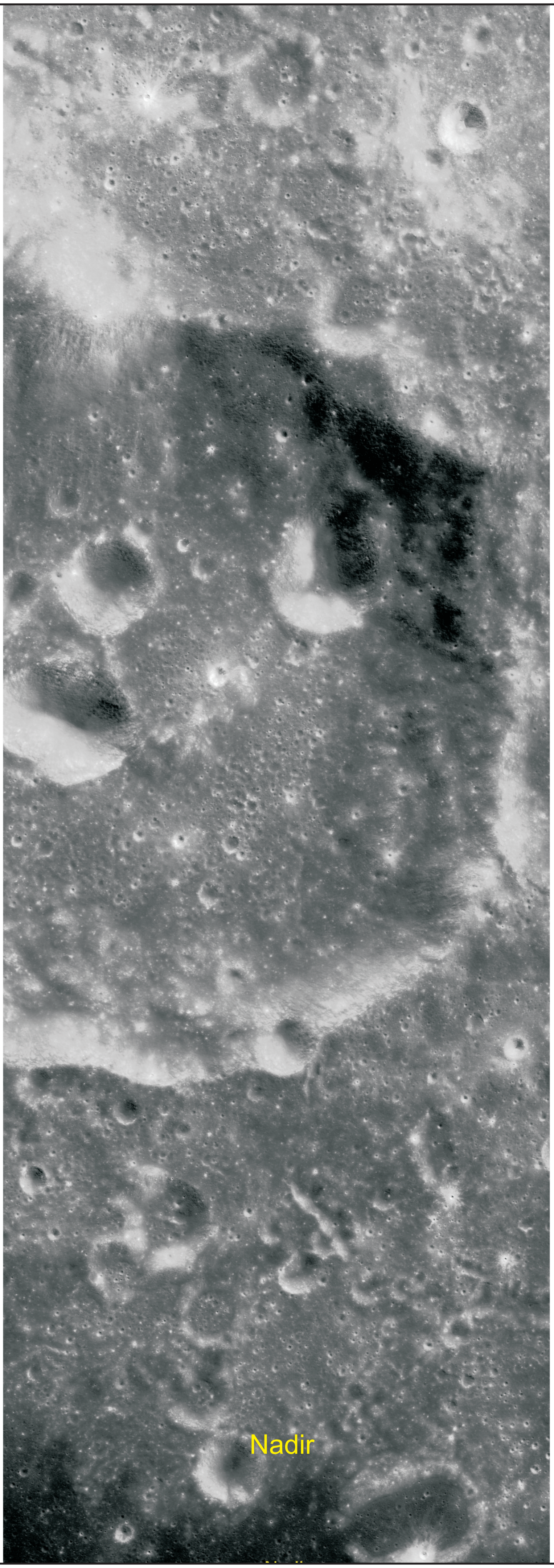
The figure is showing the three views of the Chaffee crater.

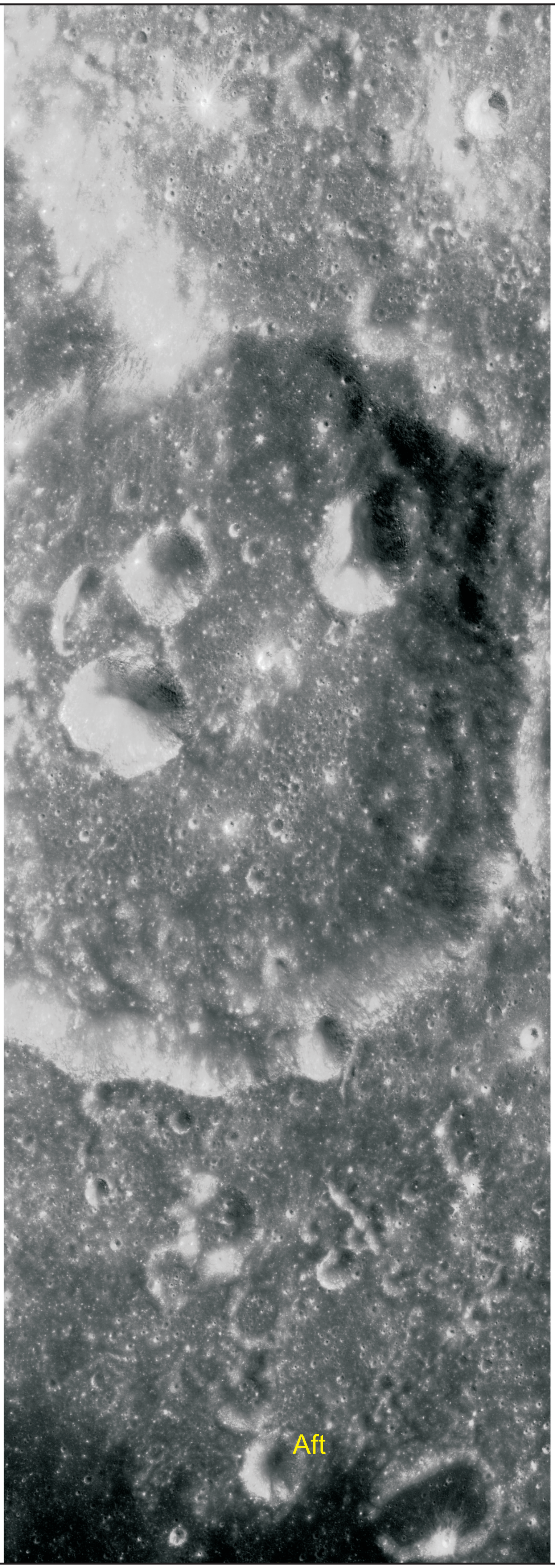
Chaffee crateris located in the southern hemisphere on the far side of the Moon. It lies within the huge walled plain Apollo. This carters is also a complex crater having diameter 49 km, rim height 2.66 km, rim width 13.69 km, floor diameter 15.91 km, central peak diameter 1.09 km and height of central peak 1 km.

Location : Chaffee Crater; Far Side; Equatorial Region

Orbit no : 3001; Date of Pass : 17-07-2009; Image Width:40 km;TMC Image Triplet


Fore


Nadir

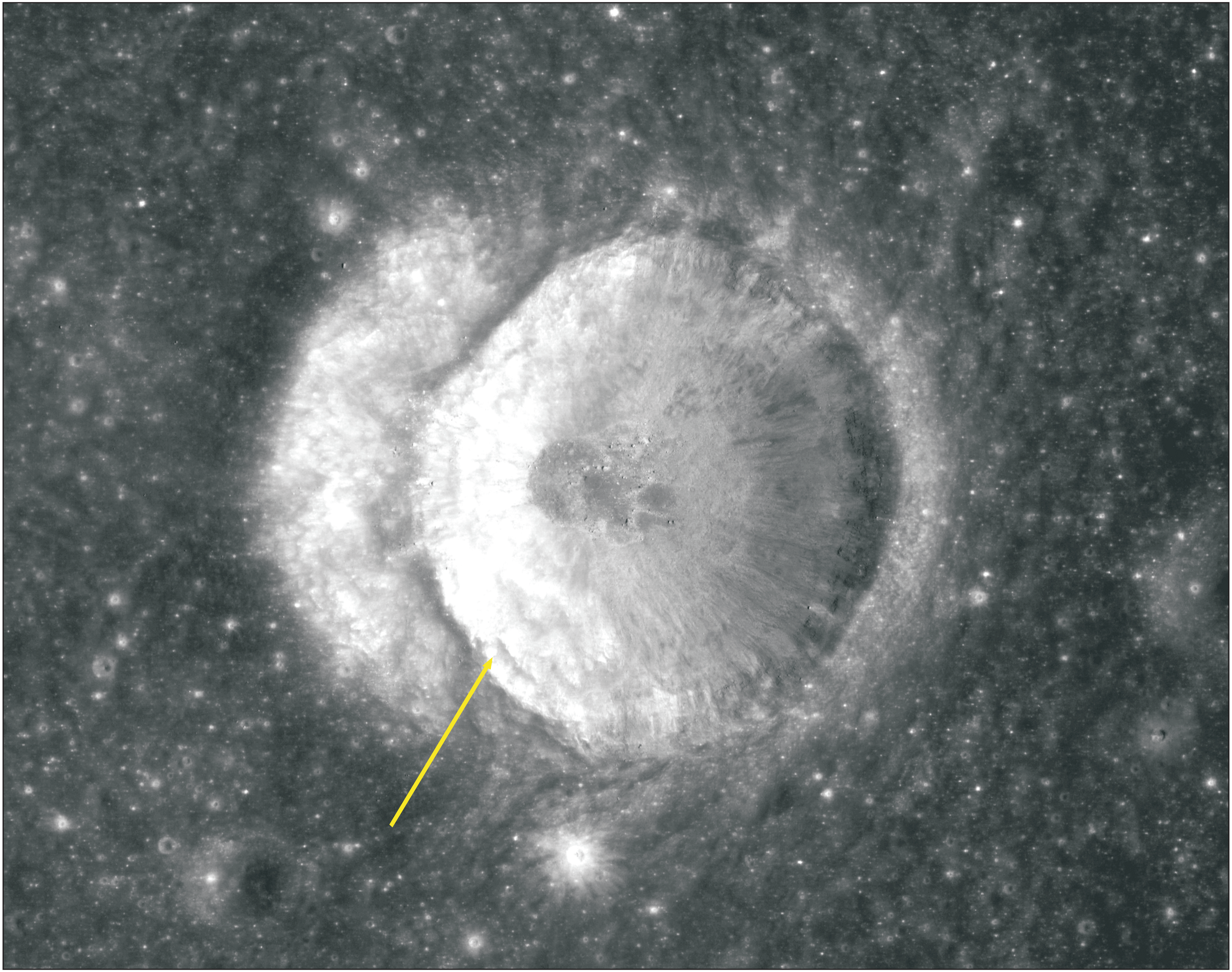

Aft

Crater Morphology : Slumped Inner Walls

The Herman-A crater, is located in Oceanus Procellarum, equatorial region on the nearside. This crater is having a diameter of 4 km , rim width 1.03 km, rim height 0.14 km and floor diameter of 0.03 km. This is also a type of simple crater.
The figure is showing slumped inner walls of the crater representing a landslide within craters.

Location : Oceanus Procellarum Area; Near Side; Equatorial Region

Orbit no : 798; Date of Pass : 13-01-2009; Scale – 1:70000;Nadir Image

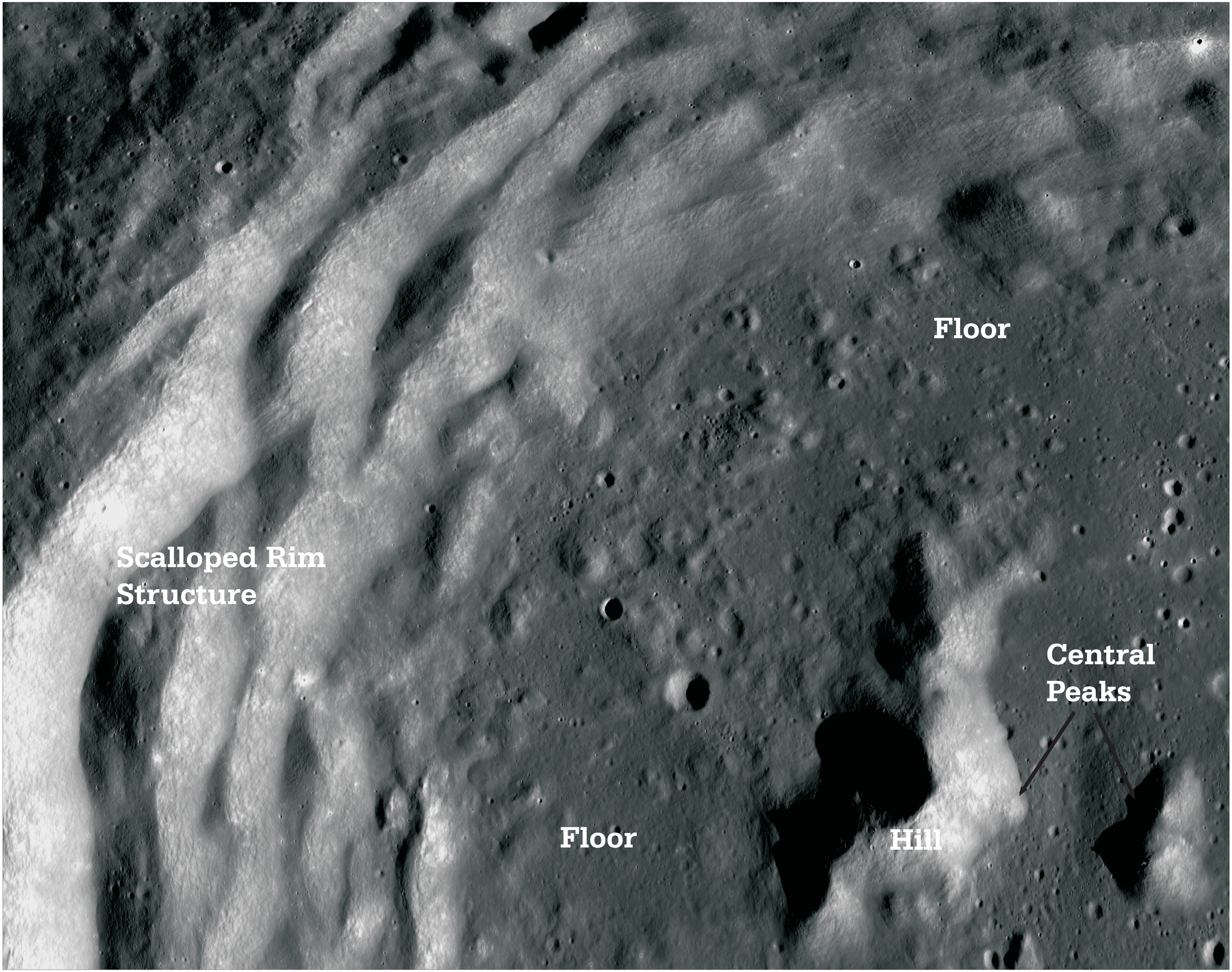


Crater Morphology : Scalloped Inner Wall Structure

Hale crater, a diameter of 83 km, is located on the southern limb of the Moon. Over half the crater lies on the far side of the Moon, and from the Earth this formation is viewed from the side.
Rim structure, central peak and floor of the crater were shown here.

Location :Hale Crater Area; Near Side; South Polar Region

Orbit no :2792; Date of Pass : 29-06-2009; Scale – 1:199500;Nadir Image

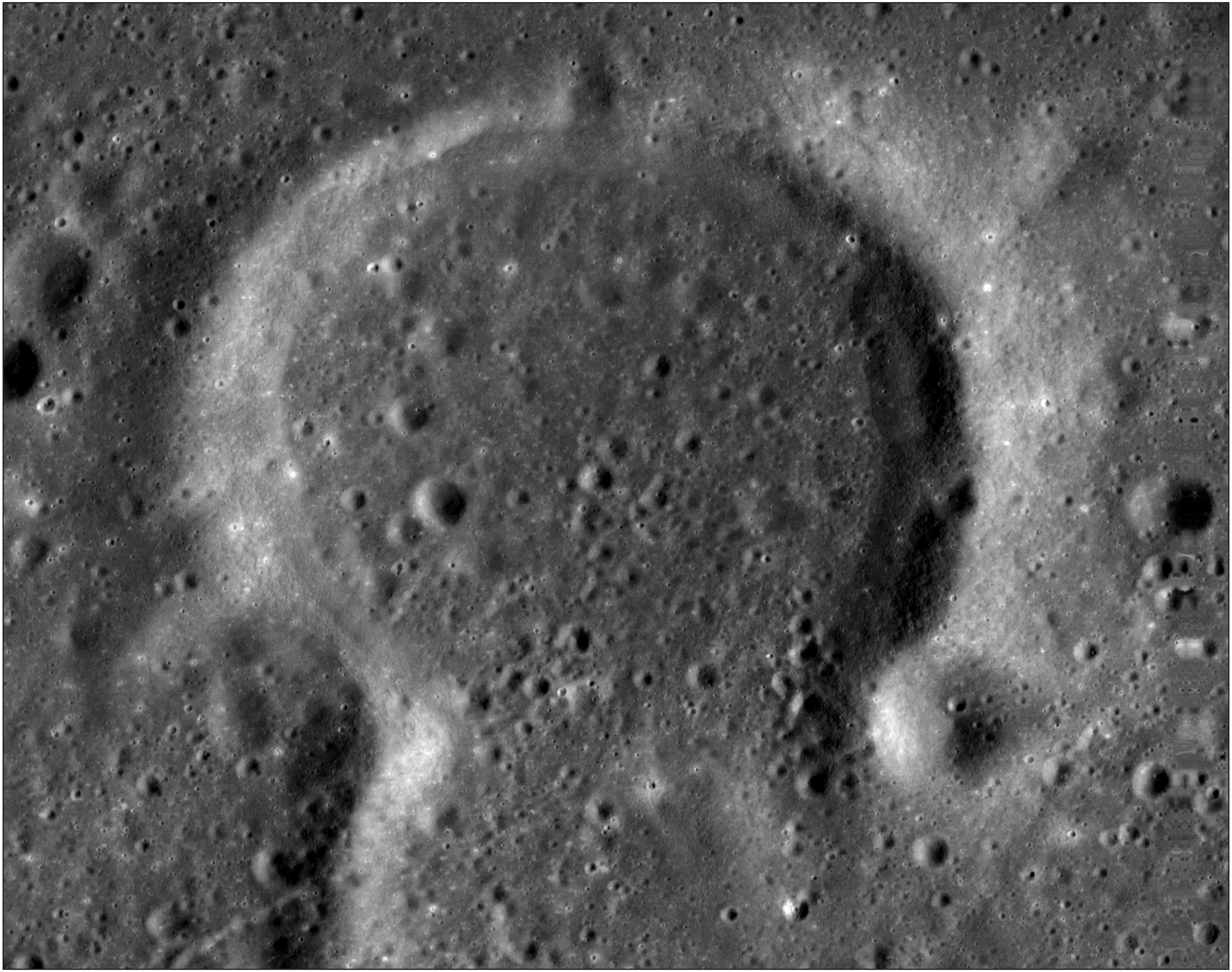

Floor
Scalloped Rim Structure
Central Peaks
Floor
Hill

Crater Morphology : Discontinuous Rim

The crater in the image shows discontinuous rim of the craters indicating older degraded or crater-rims partly buried under basaltic lava. Beneath this discontinuous rim crater, many smaller impact craters are there suggesting that the discontinuous rim crater is relatively much older at the same time the rim is also very much degraded.

Location: Near Side; Equatorial Region

Orbit No: 1105; Date of Pass: 07-02-2009; Scale – 1:50500;Nadir Image



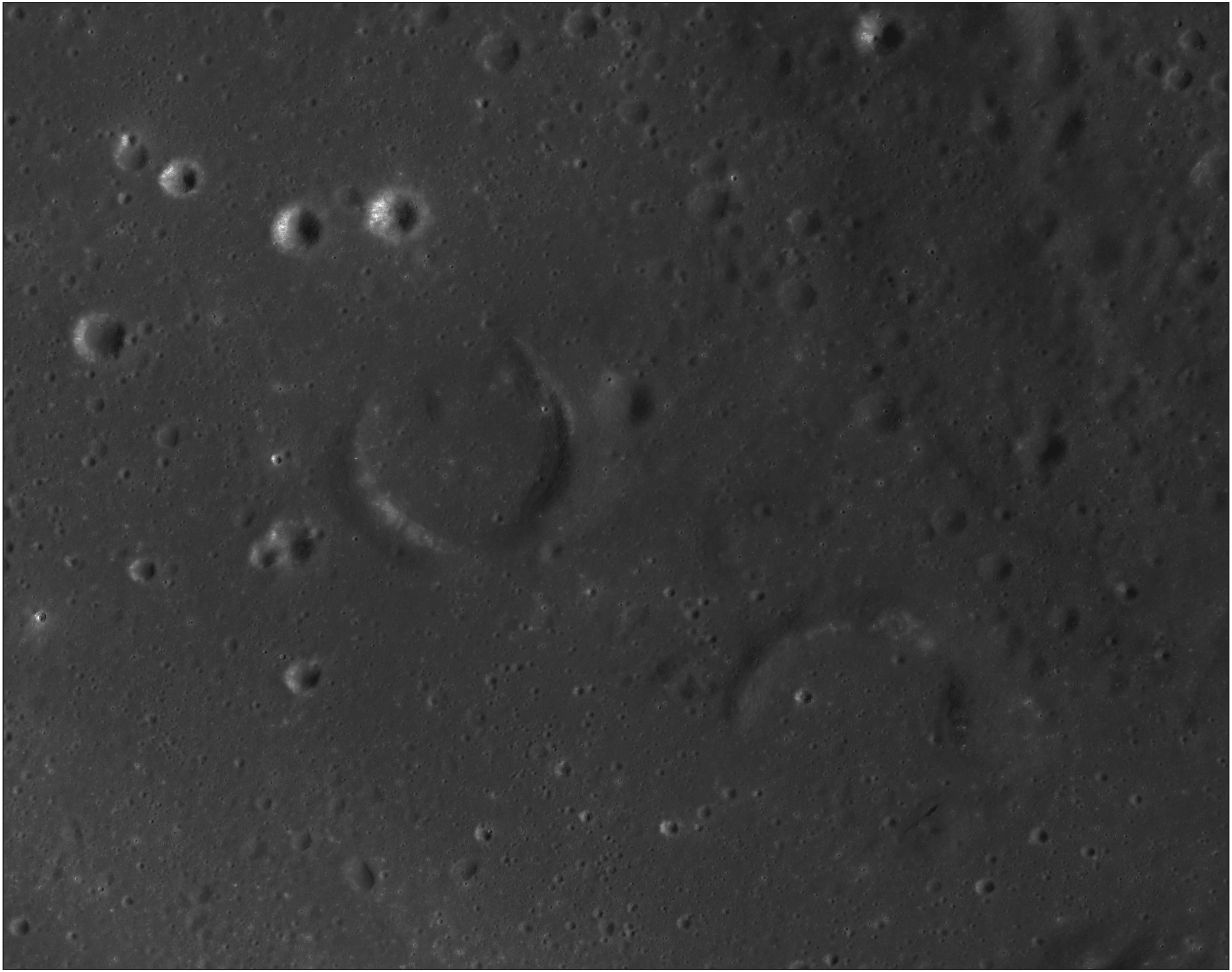
Crater Morphology : Discontinuous Rim

Euler crater, a diameter of 49 km is located in the southern half of the Mare Imbrium on the nearside.

The figure showing a part Euler crater area showing discontinuous rim of the craters indicating older degraded or crater rim partly buried under basaltic lava. The relatively fresh craters in the vicinity of the discontinuous rim craters is an indication that these smaller fresh craters are relatively younger in event.

Location : Euler Crater Area; Near Side; Equatorial Region

Orbit No: 1105; Date of Pass: 07-02-2009; Scale – 1:64500 ;Nadir Image

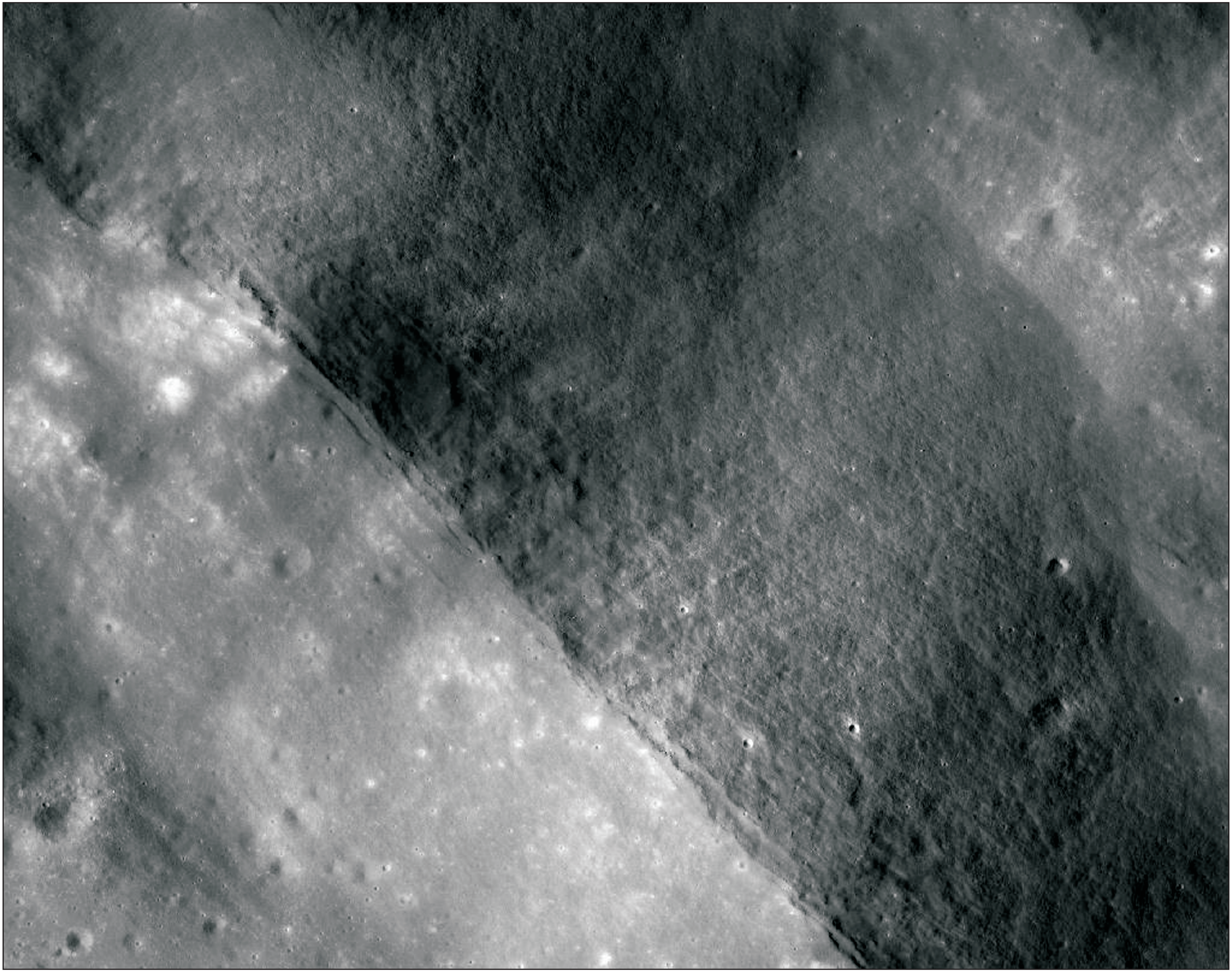


Crater Morphology: Striations on Inner Wall

This part of lunar crater shows close linear features on the crater wall. These features are seen in a few crater walls and are not common among all the craters. The walls cross sectional surface which remains preserved even when larger crater gets modified by volcanic material. The linear features are probably the remnants of frictional movement during formation of larger crater. The truncation of the linear features along a line with a surface having smooth texture is indicative of resurfacing of crater walls by successive evolutionary stages of craters. The contact of crater wall and its next floor should not be understood a tectonic/fault or structural contact.

Location : Cavalerius Crater Area; Near Side; Equatorial Region

Orbit no :1973; Date of Pass: 20-04-2009; Scale – 1:155000;Nadir Image

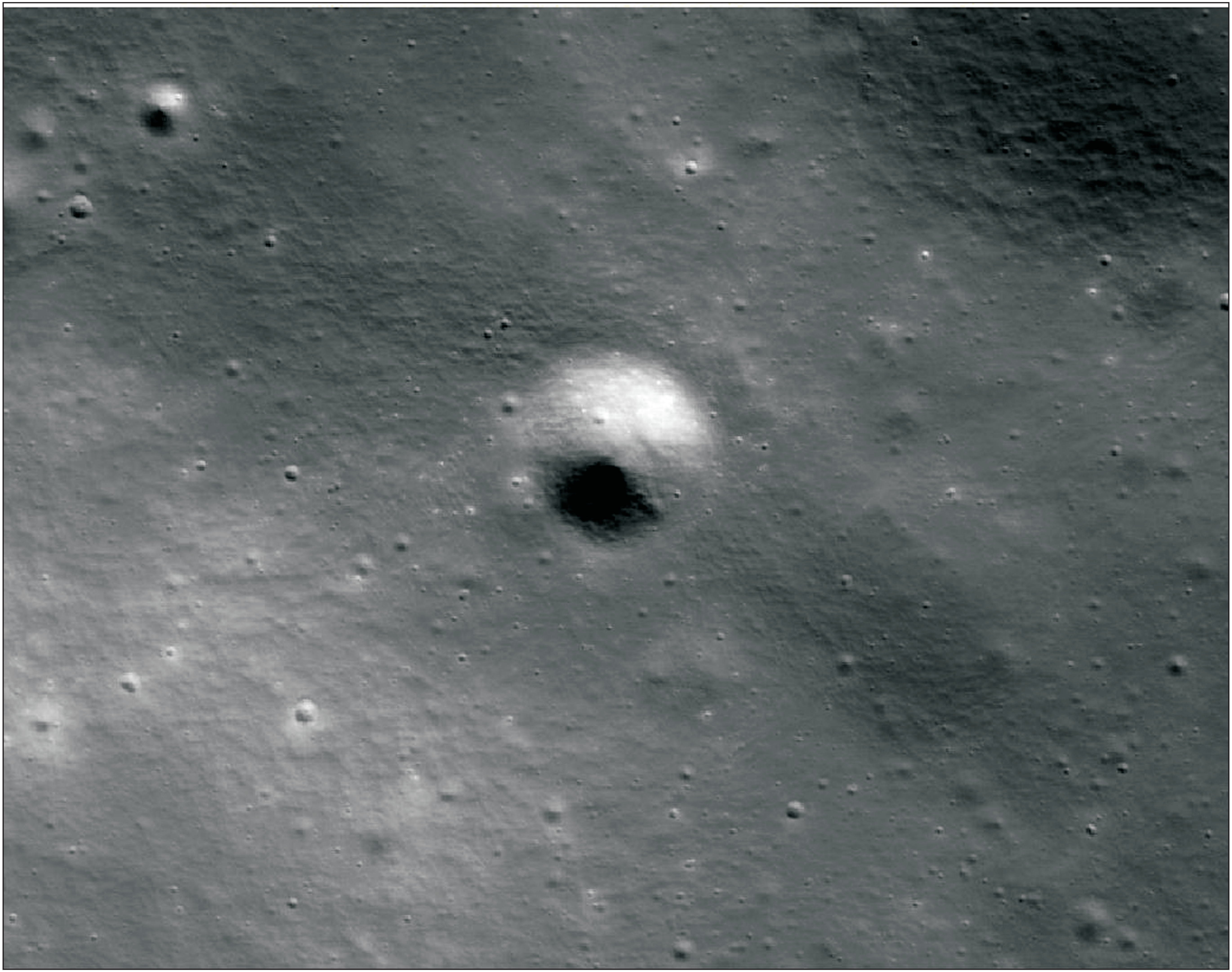


Crater Types : Simple Craters without Floor

Simple craters are small, bowl-shaped, having continuous surface of crater wall and floor. They have smooth rims, no central floor and peaks, diameter less than 20 km, rim height about 4% of diameter, rim to floor depth of about 1/5th of diameter. The floor of simple craters are underlain by breccia and contains shocked quartz. The floor is approximately 1/2 to 1/3 of rim-to-floor depth. But in earth, the simple craters are not completely circular, and the diameter range is about 3-6 km.
The image showing is a very typical simple crater. This funnel shaped crater represent small and shallow crater without central floor.

Location :Coulomb Crater Area; Far Side; Equatorial Region

Orbit no :181; DOP: 24-11-2008; Scale – 1:50000;Nadir Image

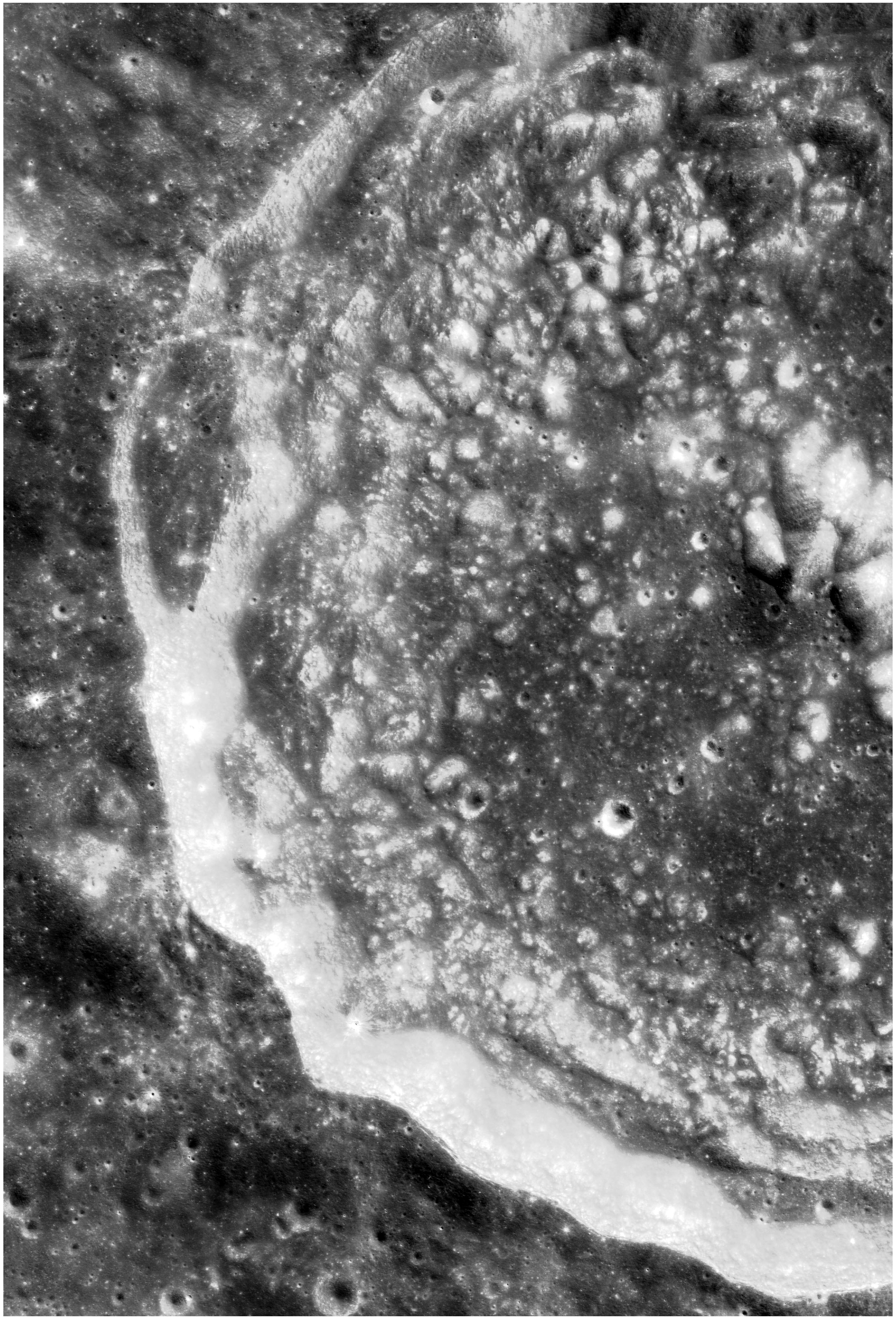


Crater Types : Crater with Floor and Central Peak

Complex crater results due to the collapse and modification of the transient cavity which is much more extensive, above a certain threshold size, varying with planetary gravity. The collapse of the transient cavity is driven by gravity, and involves both the uplift of the central region and the inward collapse of the rim. Complex craters have uplifted centers, and they have typically broad flat shallow crater floors, and terraced walls. At the largest sizes, one or more exterior or interior rings may appear, and the structure may be labeled an impact basin rather than a complex impact crater.
Dryden crater, a diameter of 59 km , is located on the southern hemisphere on the far side.

Location :Dryden Crater Area; Far Side; Equatorial Region

Orbit no :3003; DOP: 17-07-2009; Scale – 1:444000;Nadir Image

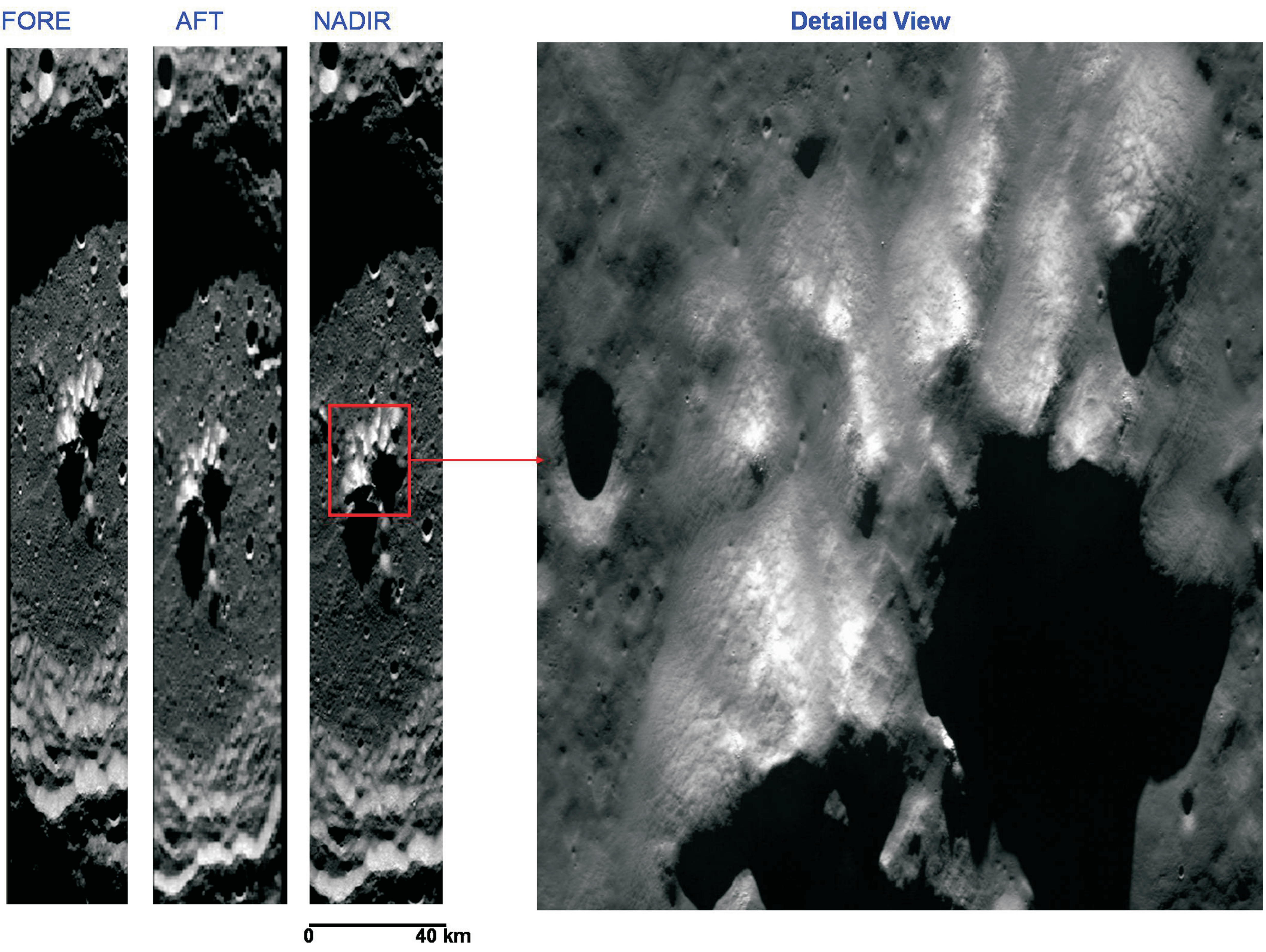


Crater types: TMC Triplet View of a complex crater

Plaskett crater, a diameter of 109 km, is located on the northern hemisphere on the far side. It lies only a few hundred kilometers south of the lunar north pole, and the sunlight it receives is at a low angle.

Location: Plaskett Crater; Far Side; North Polar region

Orbit No.:2714; Date of Pass : 22-06-2009;TMC Triplate Image

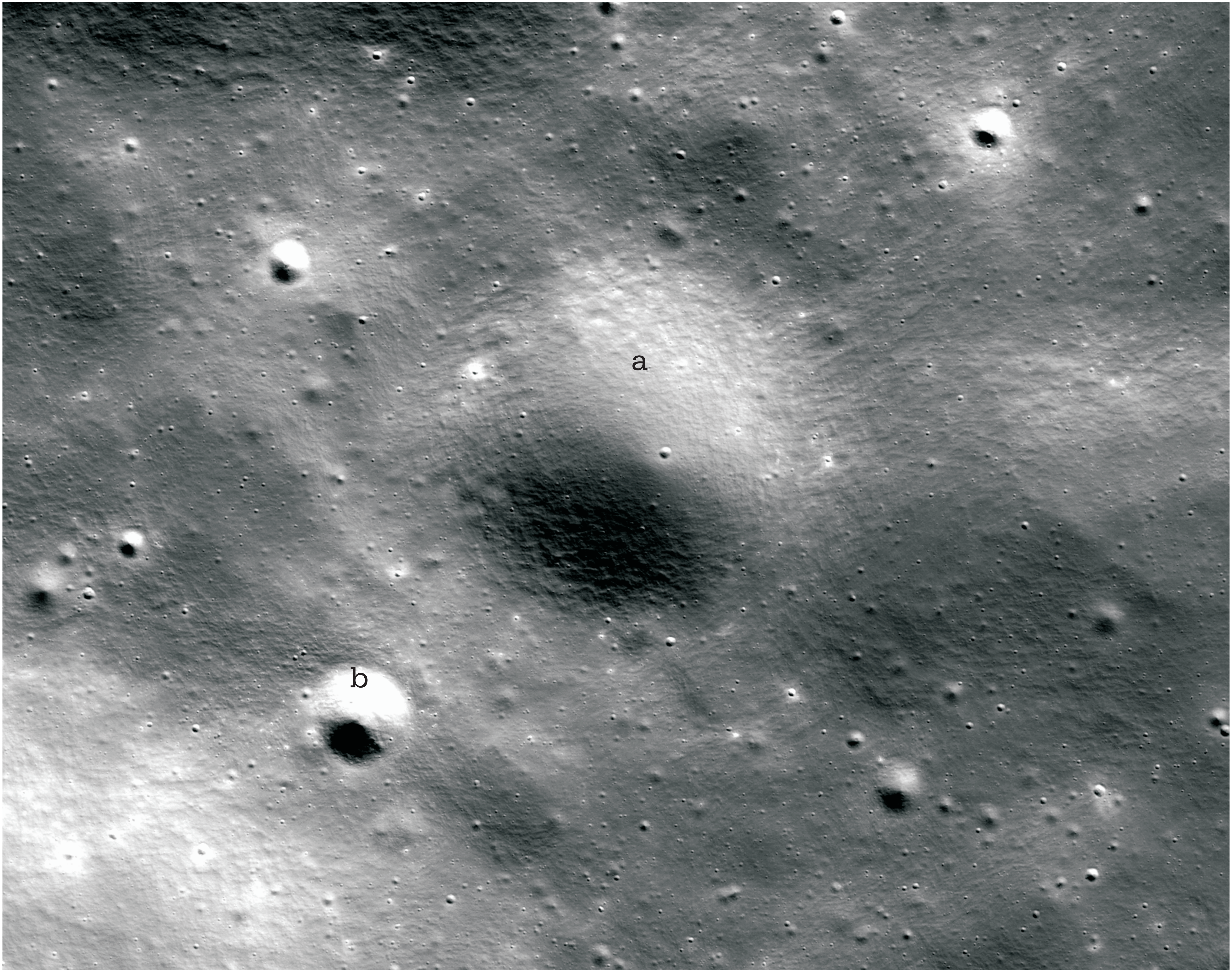

FORE
AFT
NADIR
Detailed View
0
40 km

Crater Chronology : Young and Old

Crater chronology is a very important parameter in order to interpret geologic history of the planetary surface/area.
The figure is showing a comparison in which the craters are degraded with time, signifying a relative age.
The degraded rim structure of the crater (b) is older than the younger, the sharp rim crater (a).

Location :Coulomb Crater Area; Far Side; Equatorial Region

Orbit no :181; DOP: 24-11-2008; Scale – 1:69500;Nadir Image


a
b

Crater Chronology : Ray Craters

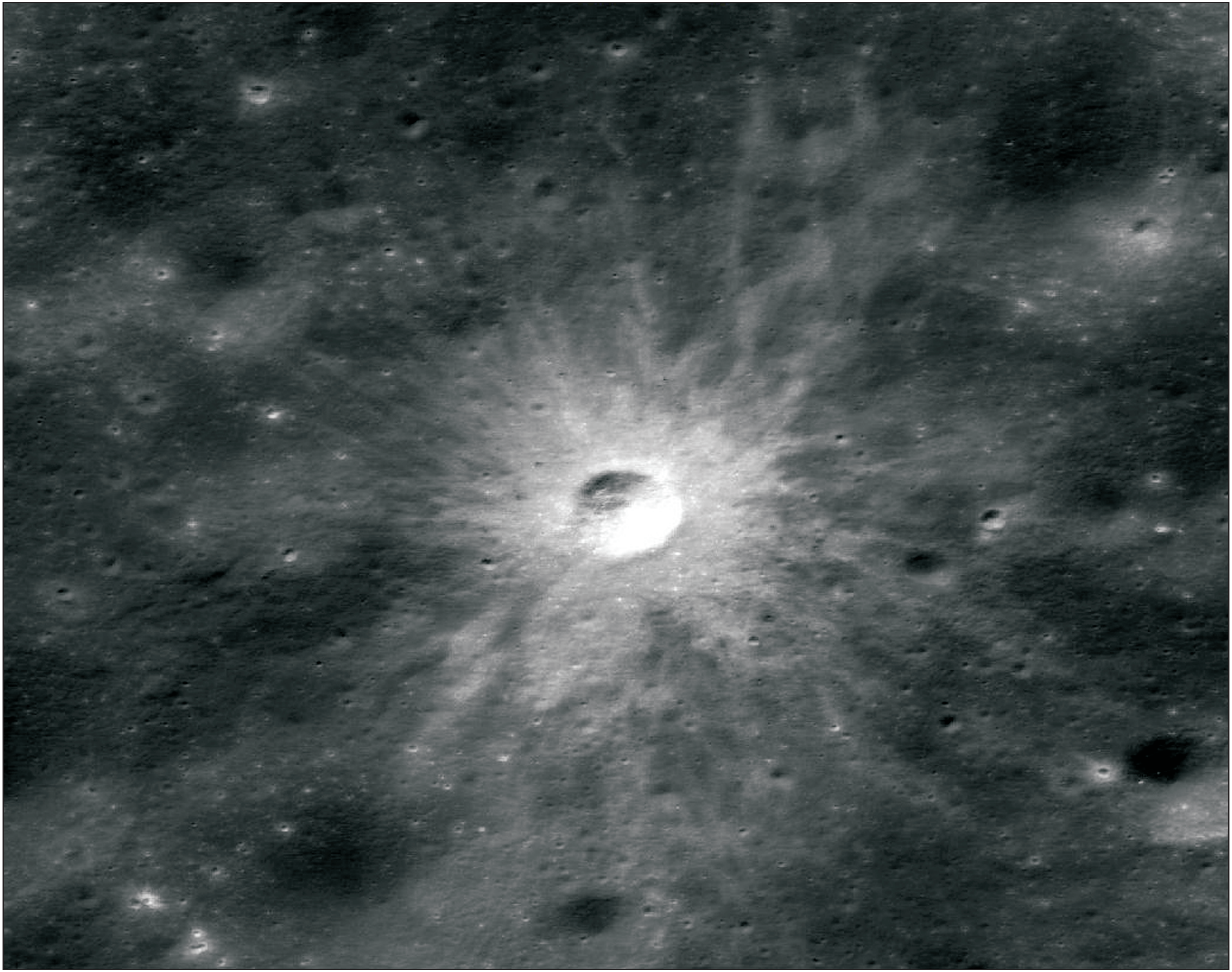
Ray craters are relatively young impact craters from which radiate streaks of material thrown out during the collision that created the crater. The ray system comprises radial streaks of fine ejecta thrown out during the formation of the impact crater, looking a bit like many thin spokes coming from the hub of a wheel. The rays can extend for lengths up to several times the diameter of their originating crater, and are often accompanied by small secondary craters formed by larger chunks of ejecta.

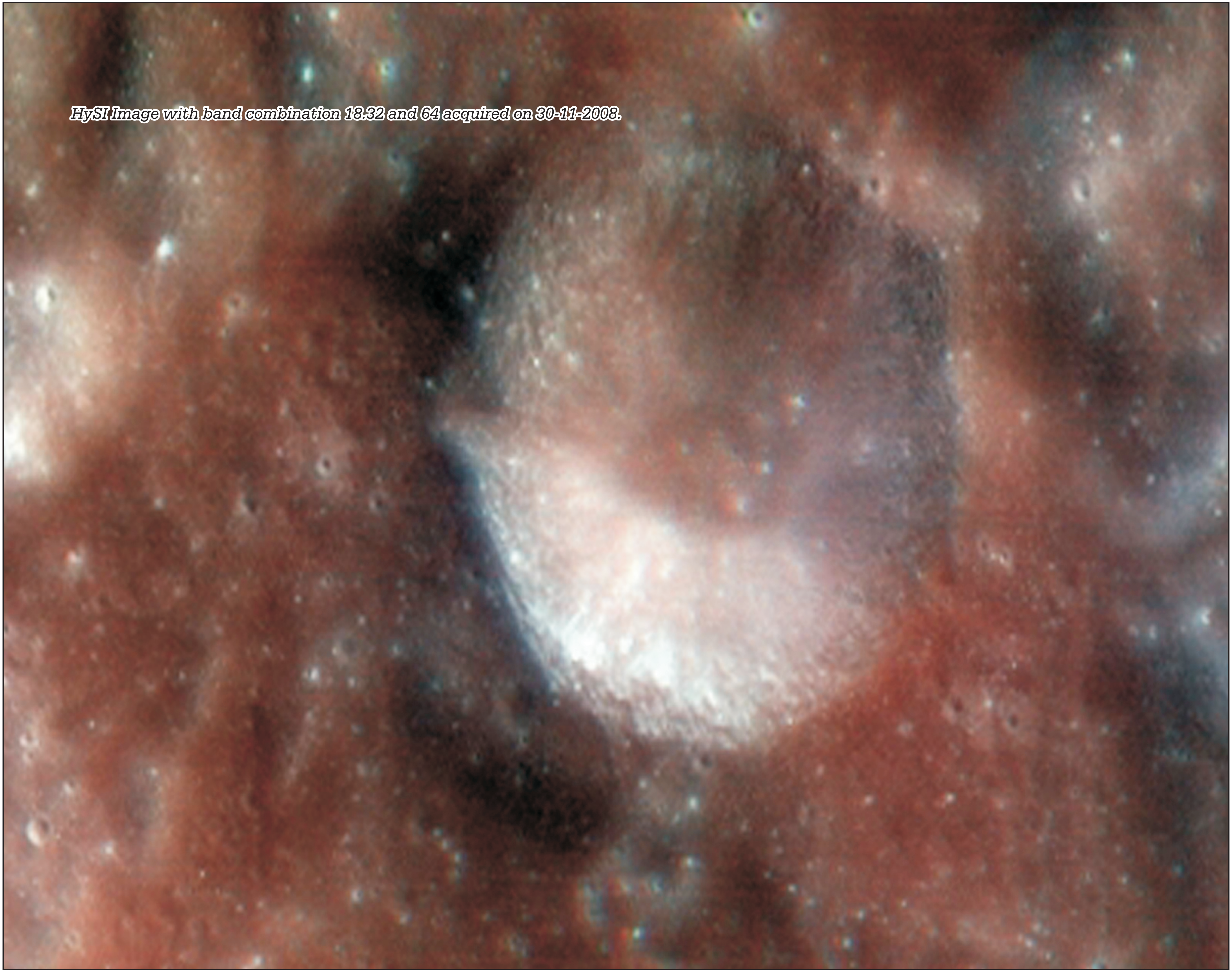
The figure showing is a ray crater, which also shows radiating streaks indicating relatively younger in nature compared to surrounding region.

It is located in Pavlov crater area. Pavlov crater, a diameter of 148 km, lies on the far side.

Location :Pavlov Crater Area; Far Side; Equatorial Region

Orbit no :280; DOP: 02-12-2008; Scale – 1:66500;Nadir Image





HySI Image with band combination 18.32 and 64 acquired on 30-11-2008.

Geological Structures

Geological structures on the Moon represent lineaments, faults, striations, graben-forms etc. Faults represent the vertical and Lateral movements of the adjacent blocks of the fractured rock mass. On the moon, they often represent the faulted circular rim structures. Lineaments on the moon represent variety of features like cooling cracks in solidified lava, graben-forms etc. These features on the Moon are significant to understand the tectonic and evolutionary history of the Moon.

Here in this section lineaments, faults (faulted rim), graben like features, scarps etc. are displayed.

These features are also found in other planets (Mercury, Venus, Mars, Jupiter, Saturn)

Features	Mercury	Venus	Mars	Jupiter	Saturn
Faults	✓	✓	✓	✓	✓
Graben	✓	✓	✓	✓	✓
Lineaments	✓	✓	✓	✓	✓
Rilles	✓	✓	✓	✓	✓

Structures : Network of Lineaments

Fabric of criss-crossing natural straight line features developed mostly during the cooling of the lava. It denotes the volcanic flooding and settling history of lava. A graben is a depressed block of land bordered by parallel faults and fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement.A graben is the result of a block of land being downthrown producing a valley with a distinct scarp on each side. Graben often occur side-by-side with horsts. Horst and graben structures are indicative of tensional forces and crustal stretching.Graben are produced from parallel normal faults, where the hanging wall is downthrown and the footwall is upthrown. The faults typically dip toward the center of the graben from both sides. Horsts are parallel blocks that remain between grabens, the bounding faults of a horst typically dip away from the center line of the horst.

Location : Near Side; North Polar Region

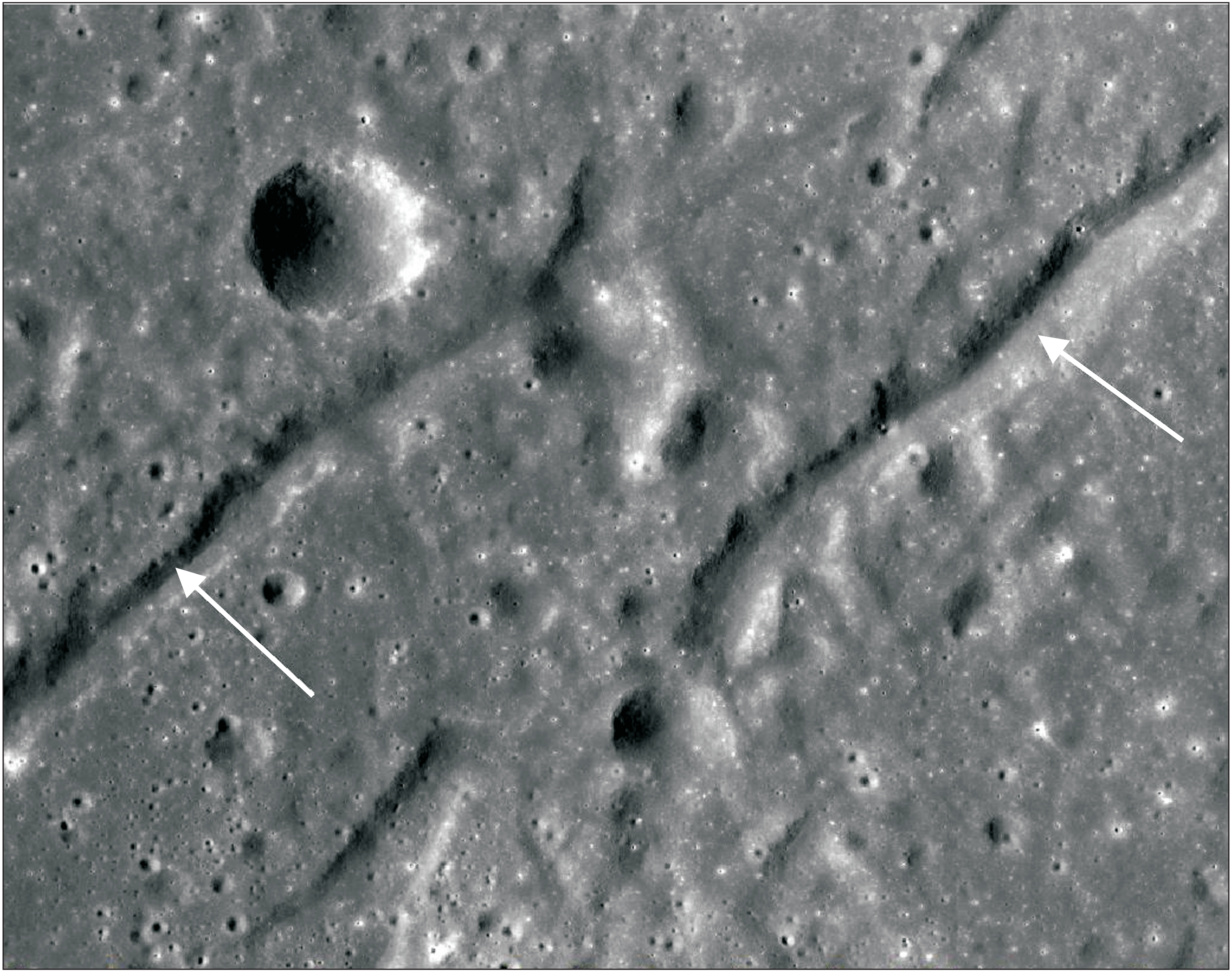
Orbit no : 90; DOP: 16.11.2008; Scale- 1:141500;Nadir Image

Structures : Lineaments

The dark surface shown here is of rich ferromagnesian basaltic composition. The linear features are similar to graben like features seen on the earth surface. The geometrical shape of these features are indicative of crustal deformation. . However these structures are yet not filled with any subsequent volcanic mass. The discontinuity of these structures indicate that surface is older than these features otherwise these valleys could have filled by the volcanic flows.

Location : Near Side; Equatorial Region

Orbit no : 1973; Date of Pass: 20-04-2009; Scale- 1:160000 ;Nadir Image

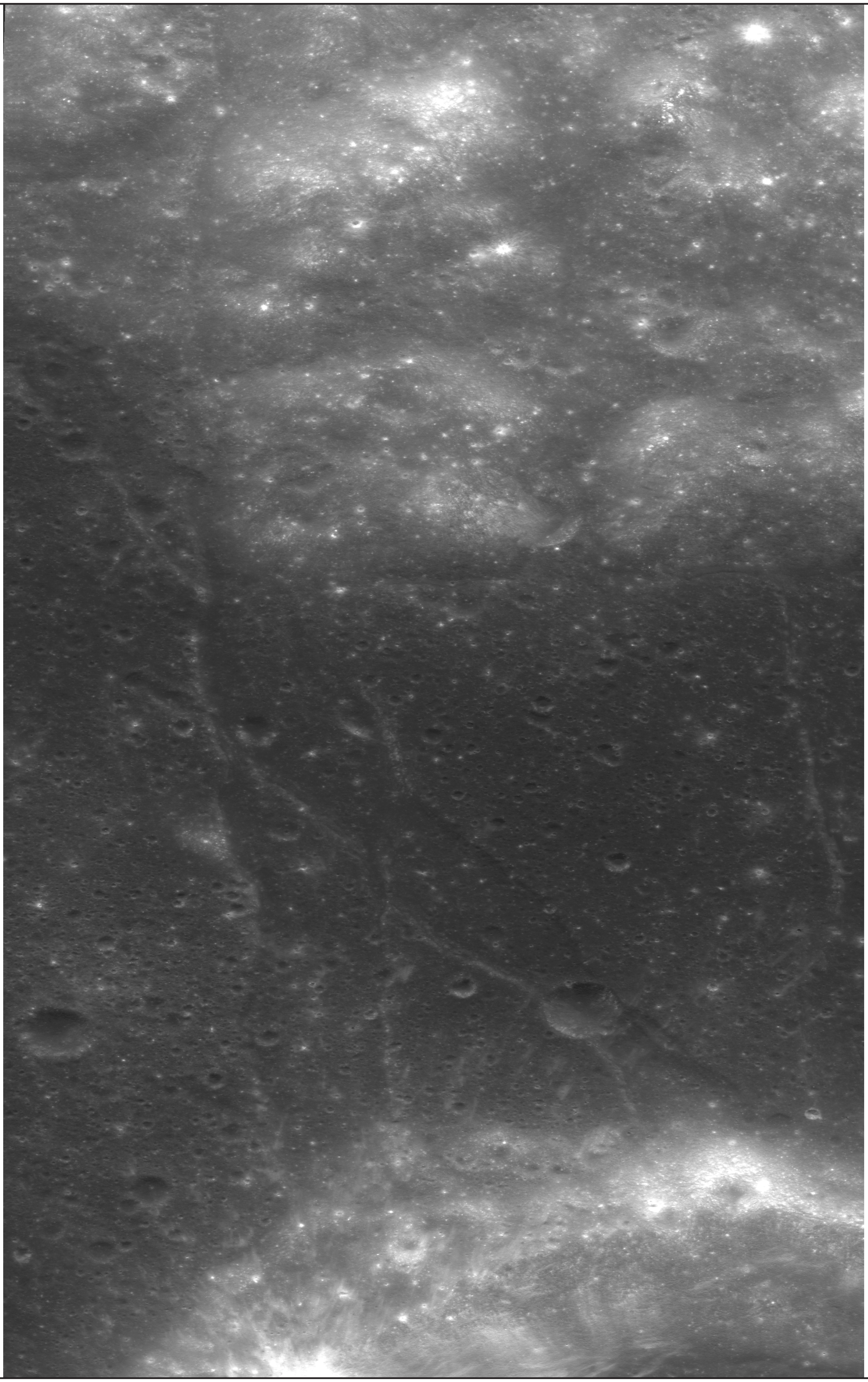


Structures : Lineaments

The lineaments in the image represents parallel faults / graben structures on Moon surface.

Location : Near Side; Equatorial Region

Orbit no :440; Date of Pass: 15-12-2008; Scale – 1:324500;Nadir Image

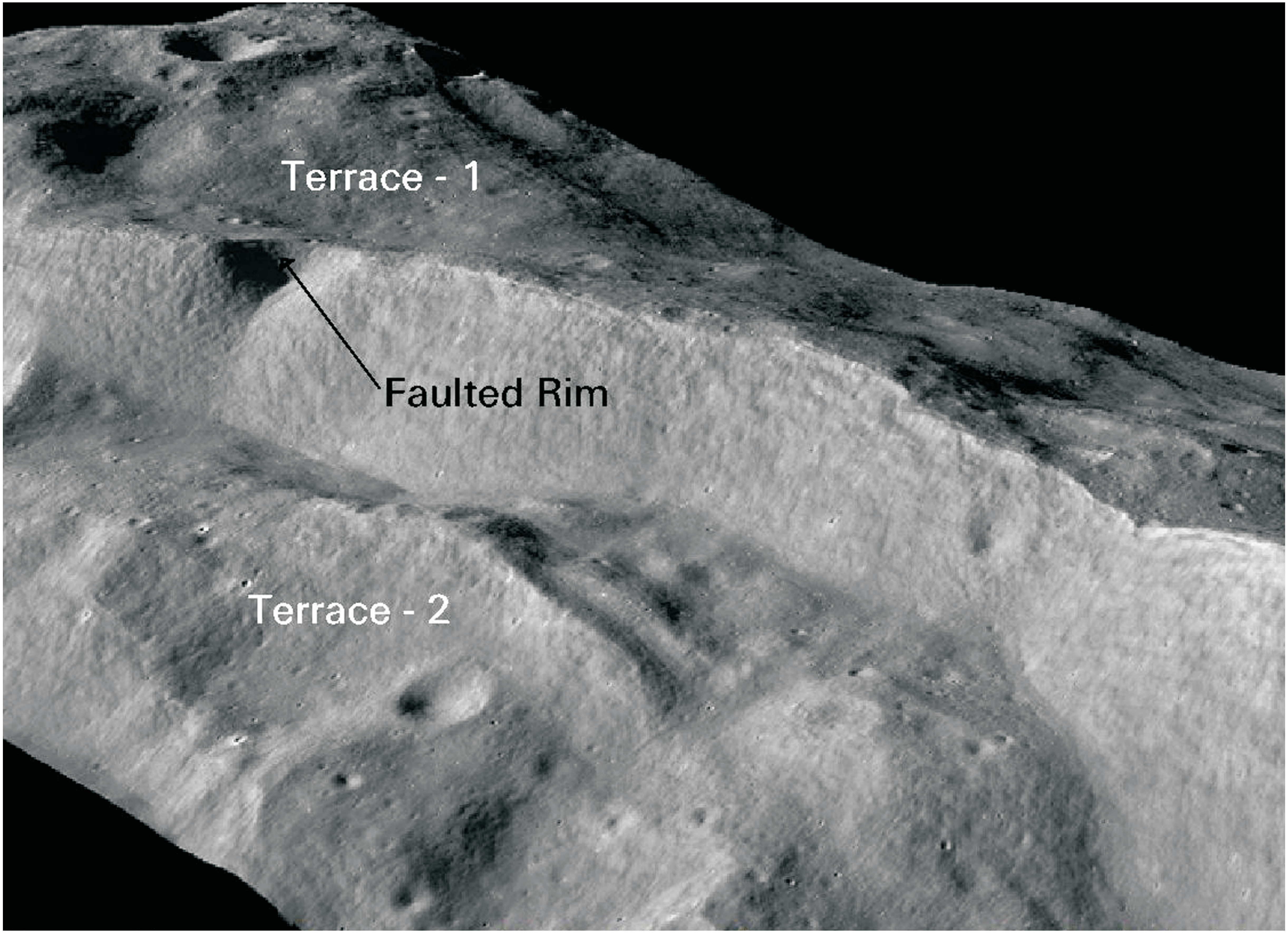


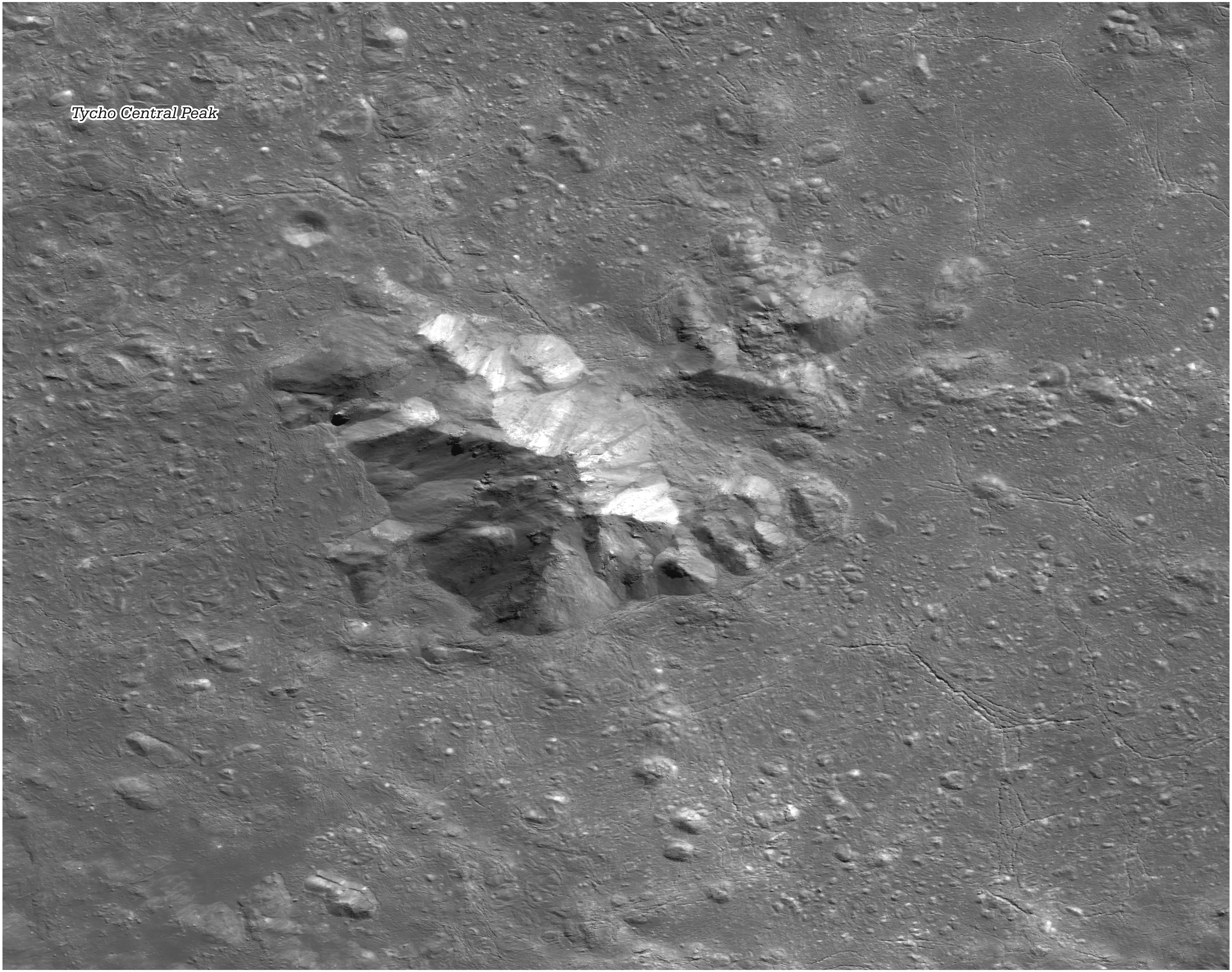
Structures : Faults

The figure is showing terraced Inner wall structure of faulted rim of Moretus crater.
Moretus crater located in the heavily cratered highland region near the south pole of the Moon. The Moretus crater is a complex crater having diameter 111 km, rim height 3.68 km, rim width 27.13 km, floor diameter 44.17 km , and the diameter of the central peak 1.08 km.

Location : Moretus Crater Area; Near Side; South Polar Region

Orbit no :57; Date of Pass: 15-11-2008; Image Drape View;Nadir Image


Terrace - 1
Faulted Rim
Terrace - 2


Tycho Central Peak

Rilles

Rilles (German for 'groove') on the moon, once believed to be dried river channels; however they mostly represent the collapsed lava tubes of different size and shape. They are very significant in understanding the volcanic flow direction, re-constructing the volcanic history.

Sinuous rilles meander in a curved path like a mature river, and are commonly thought to be the remains of collapsed lava tubes or extinct lava flows. They usually begin at an extinct volcano, then meander and sometimes split as they are followed across the surface.

Arcuate rilles have a smooth curve and are found on the edges of the dark lunar maria. They are believed to form when the lava flows that created a mare cool, contract, and sink.

Straight rilles follow long, linear paths and are believed to be grabens, sections of the crust that have sunk between two parallel faults. These can be readily identified when they pass through craters or mountain ranges.

Features	Mercury	Venus	Mars	Jupiter	Saturn
Rilles	sinuous	sinuous	sinuous	Loop rille (Europa, a Moon)	Network of dark rilles (Titan, a Moon)

Interestingly, the rilles with un-collapsed and intact roof-tops are potential sites for the future human settlement on the moon as they would protect them from the lethal shower of falling objects, the extreme surface temperatures during the day and the harmful cosmic rays.

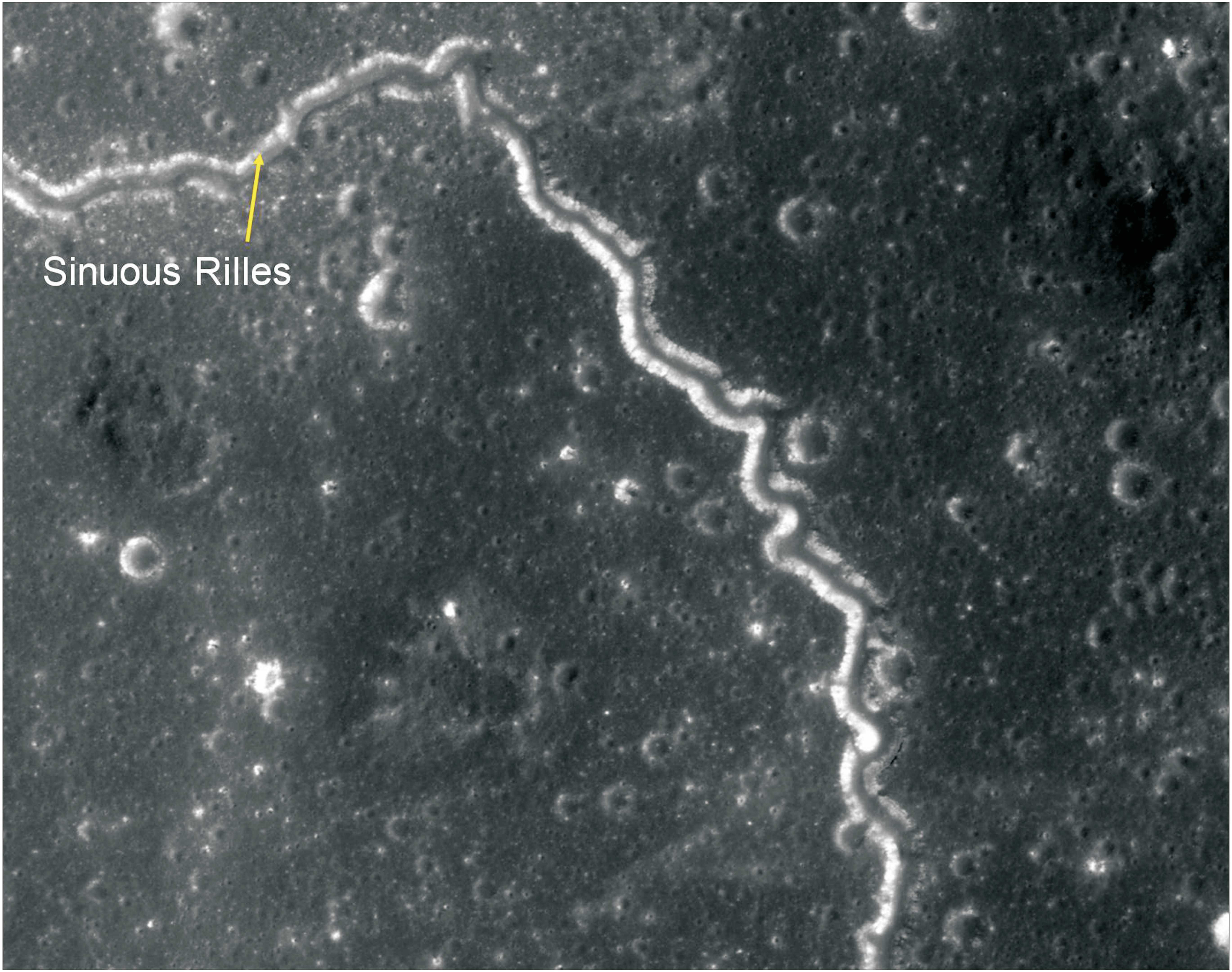
In this section sinuous rilles of various shapes like linear, arcuate, sinuous rilles are displayed.

Rilles : Sinuous Rilles

Sinuous rilles meander in a curved path like a mature river, and are commonly thought to be the remains of collapsed lava tubes or extinct lava flows. They usually begin at an extinct volcano, then meander and sometimes split as they are followed across the surface. The sinuous rille showing is Rima Gallileai in Oceanus procellarum on the nearside.

Location : Oceanus Procellarum Area; Near Side; Equatorial Region

Orbit :798, Date of Pass :13-01-2009; Scale – 1:161000;Nadir Image


Sinuous Rilles

Rilles : Sinuous Rilles

Sinuous Rilles indicates a serpentine shape, mostly showing the collapsed roof of lava flows. They may extend over longer distance and sometimes do not represent tappering and shallowing , probably indicating structural implications.

Location : Oceanus Procellarum Area; Near Side; Equatorial Region

Orbit :798, Date of Pass :13-01-2009; Scale – 1:161000;Nadir Image

Rilles : Linear Rille

Straight rilles follow long, linear paths and are believed to be grabens, sections of the crust that have sunk between two parallel faults. These can be readily identified when they pass through craters or mountain ranges. Linear rille indicating a straight flow of the lava, tapering and shallowing away from parent crater.
Tobias Mayer crater is located at the western end of the Montes Carpatus mountain range along the southern edge of Mare Imbrium. To the west is the Oceanus Procellarum, and to the south is Mare Insularum. The crater is located a couple of hundred kilometers to the northwest of the prominent crater Copernicus.

Location : Tobias Mayer Crater Area; Near Side, Equatorial Region

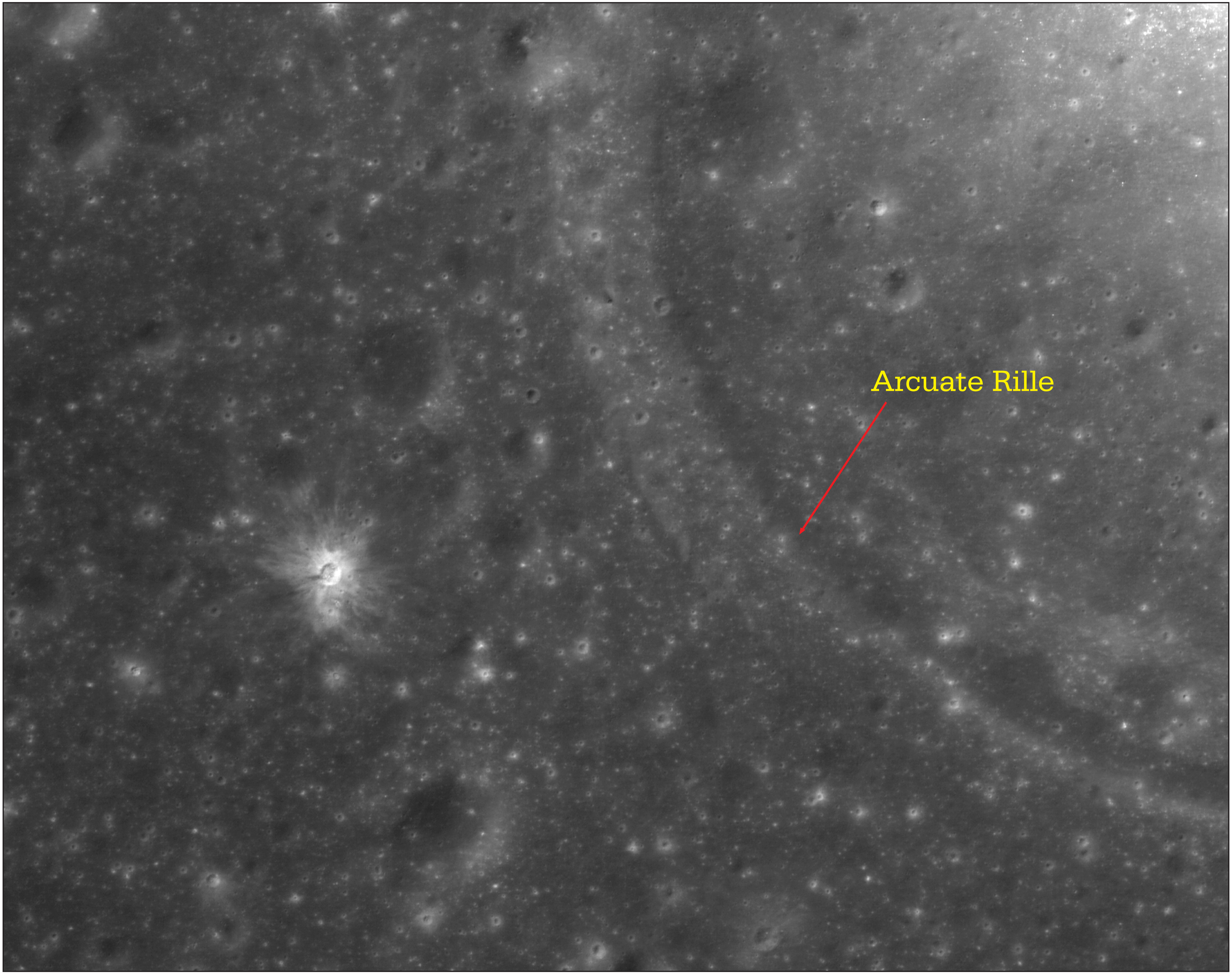
Orbit :1105, Date of Pass :07-02-2009; Scale – 1:119500;Nadir Image

Rilles : Arcuate Rilles

Arcuate rilles have a smooth curve and are found on the edges of the dark lunar maria. They are believed to form when the lava flows that created a mare cool, contract, and sink.
This Arcuate rille indicating a flow of the lava in an arc, tapering and shallowing away from the parent crater, which is located in Mare Orientale of Farside.
Mare Orientale is one of the most striking large scale lunar features, resembling a target ring bull's-eye.

Location : Mare Orientale Area;Far Side, Equatorial Region

Orbit :166; Date of Pass :23-11-2008; Scale – 1:74500;Nadir Image

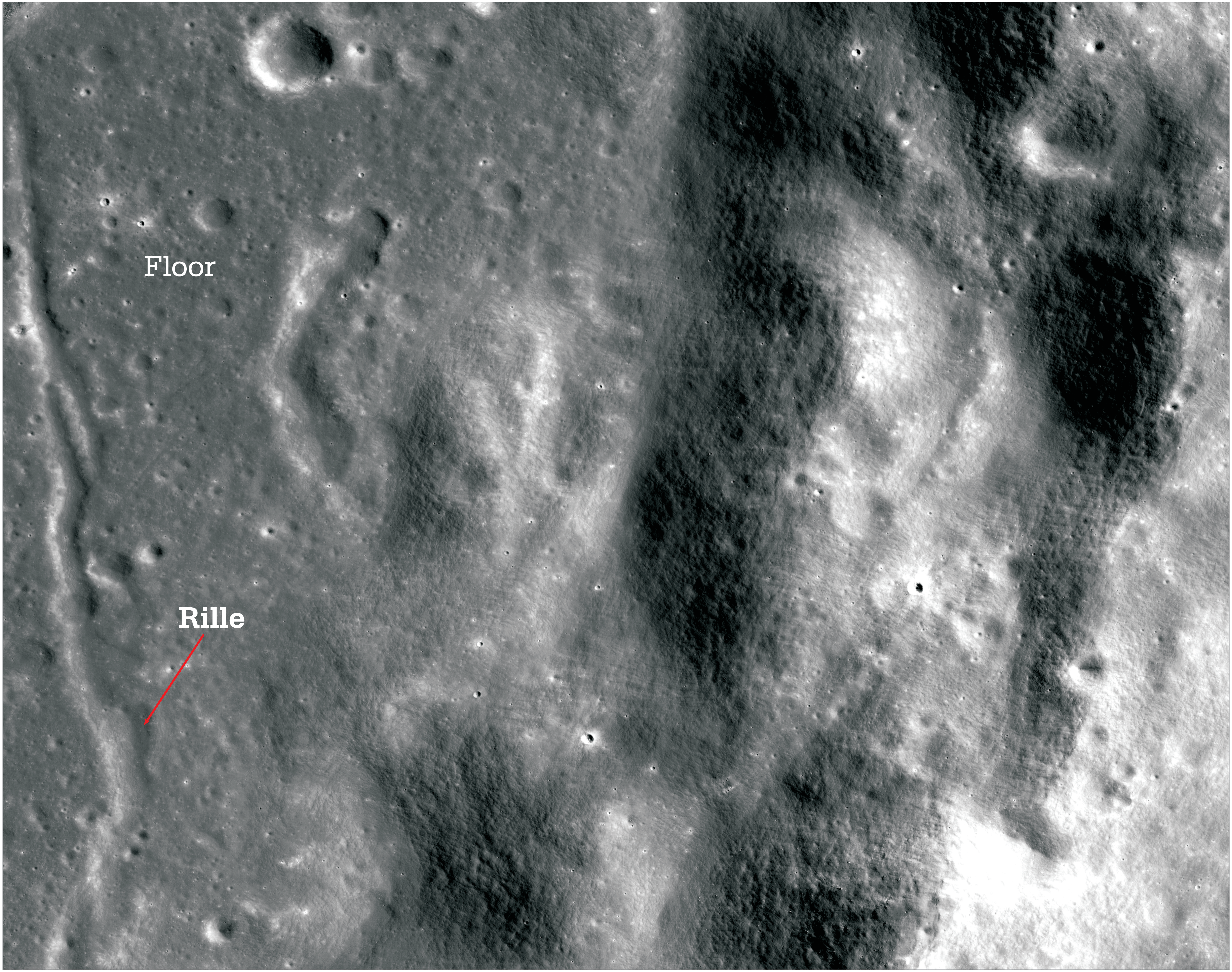

Arcuate Rille

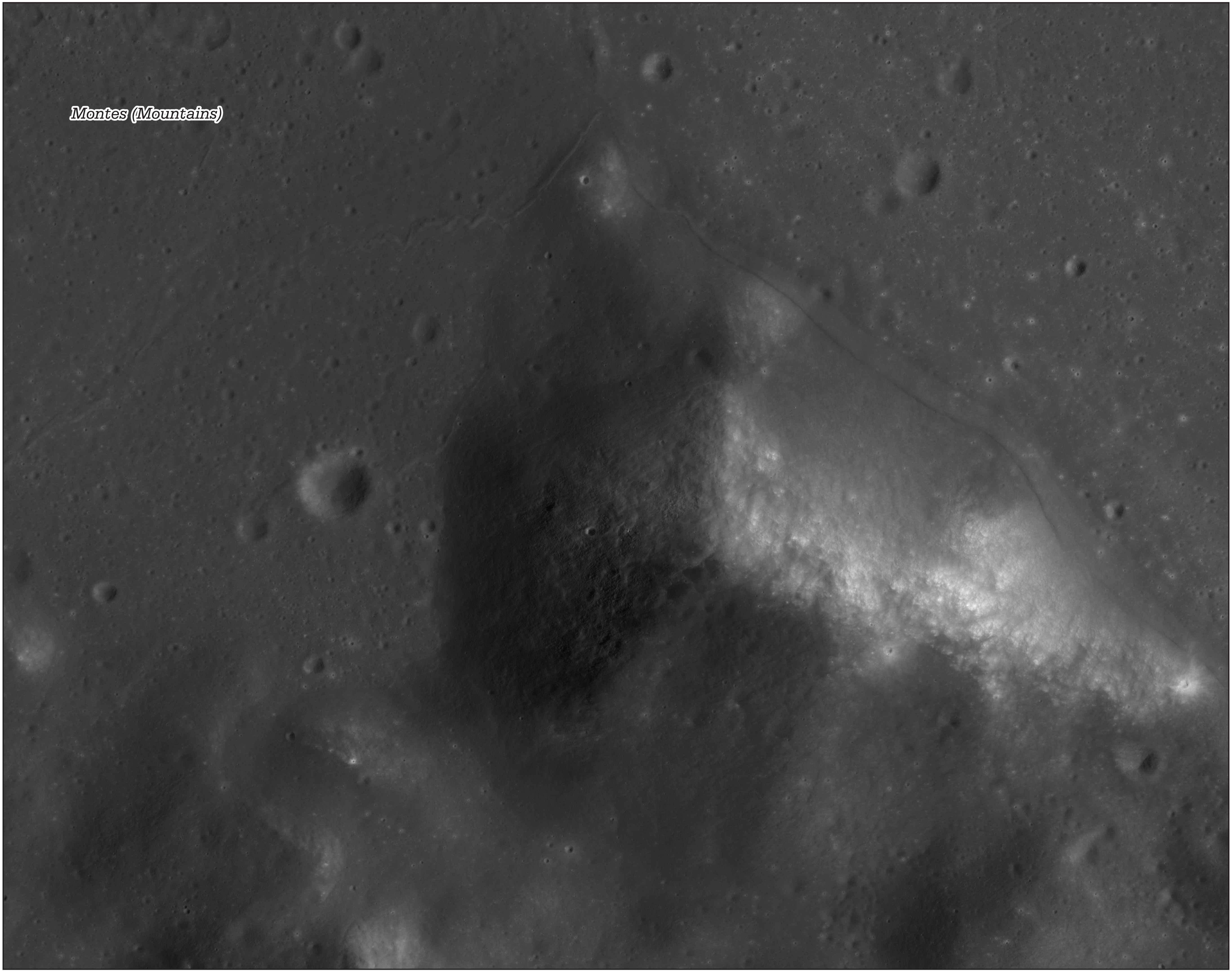
Rilles : Arcuate Rilles

Arcuate Rille indicating a flow of the lava in an arc, tapering and shallowing away from the parent crater.

Location : Campanus Crater Area; Near Side, Equatorial Region

Orbit :1102; Date of Pass :07-02-2009; Scale – 1:155500;Nadir Image


Floor
Rille


Montes (Mountains)

Important Features

This section includes some interesting observations made from the TMC camera such as Apollo landing sites, location of the Indian National Flag on Moon and some other interesting geological features

Apollo 15 Landing Site

The Apollo program was the American spaceflight endeavor which landed the first humans on Earth's Moon. Apollo 11 mission on July 20, 1969 landed on the Moon for the first time. Five subsequent Apollo missions also landed astronauts on the Moon, the last in December 1972. In these six Apollo spaceflights, 12 men walked on the Moon. These are the only times humans have landed on another celestial body.
The Apollo missions landed on Moon are as:

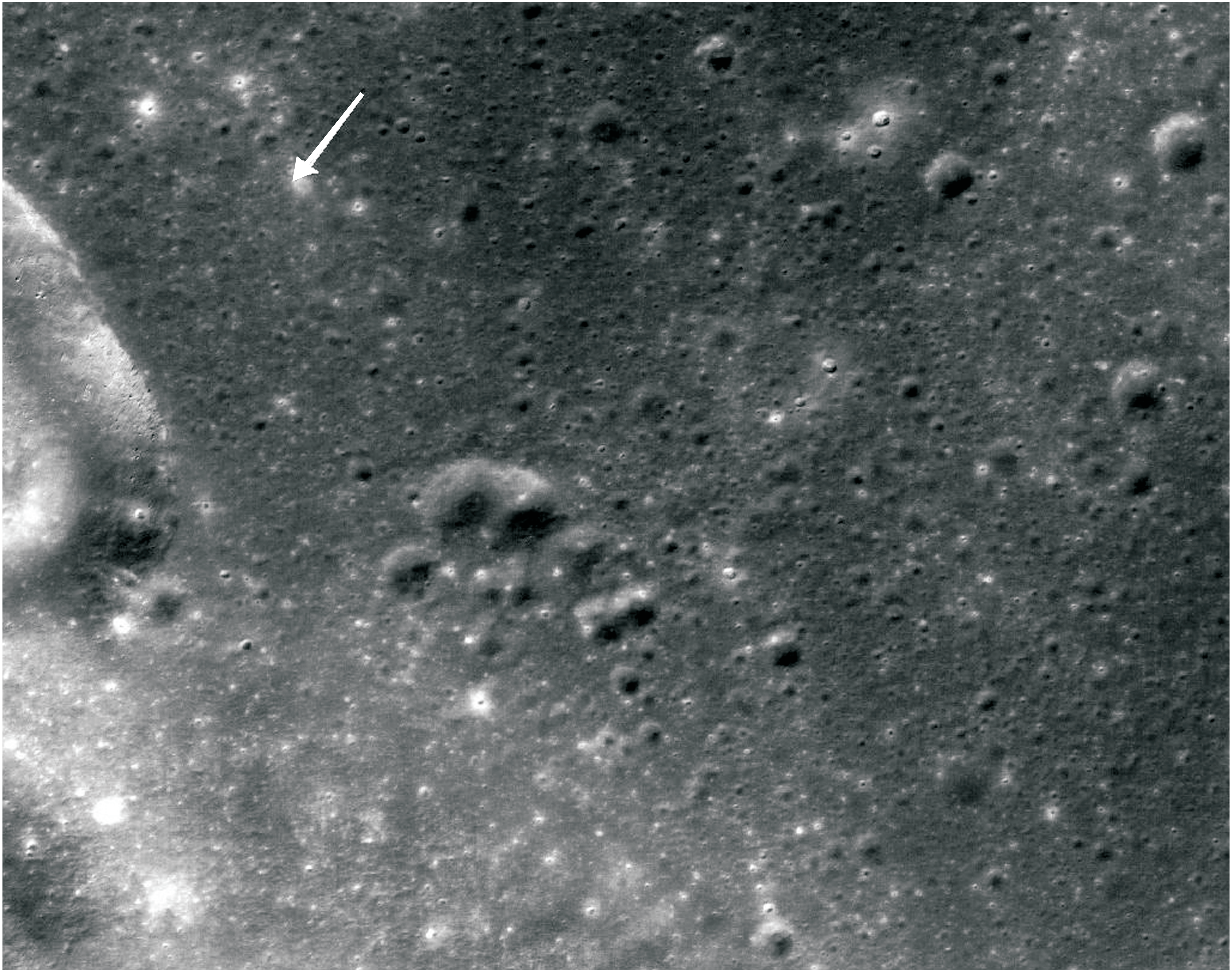
Mission Name	**Landing Date**	**Landing Site**
Apollo 11	20 July 1969	Sea of Tranquility
Apollo 12	19 November	Ocean of Storms
Apollo 14	5 February 1971	Fra Mauro
Apollo 15	30 July 1971	Hadley Rille
Apollo 16	21 April 1972	Descartes Highlands
Apollo 17	11 December 1972	Taurus-Littrow

Apollo 15 was the ninth manned mission in the Apollo program, the fourth mission to land on the Moon and the eighth successful manned mission. It was the first of what were termed "J missions", long duration stays on the Moon with a greater focus on science than had been possible on previous missions. It was also the first mission where the Lunar rover was used.The mission began on July 26, 1971, and concluded on August 7. NASA called it the most successful manned flight ever achieved. They collected a total of 77 kg (170 lbs) of lunar surface material. Apollo 15 was the first mission to carry the SIM (Scientific Instrument Module) bay, which contained a panoramic camera, gamma ray spectrometer, mapping camera, laser altimeter and mass spectrometer and this mission’s photographs and observations led to the selection of Taurus Littrow as the future Apollo 17 landing site.The mission was the first not to land in a Lunar mare, instead landing near Hadley rille in an area of the Mare Imbrium called Palus Putredinus (Mare Imbrium) (Marsh of Decay).

Arrow shows the spot on Lunar surface where Apollo-15 landed.

Location : Near Side, Equatorial Region

Orbit :737, Date of Pass :09-01-2009; Scale – 1:80000;Nadir Image

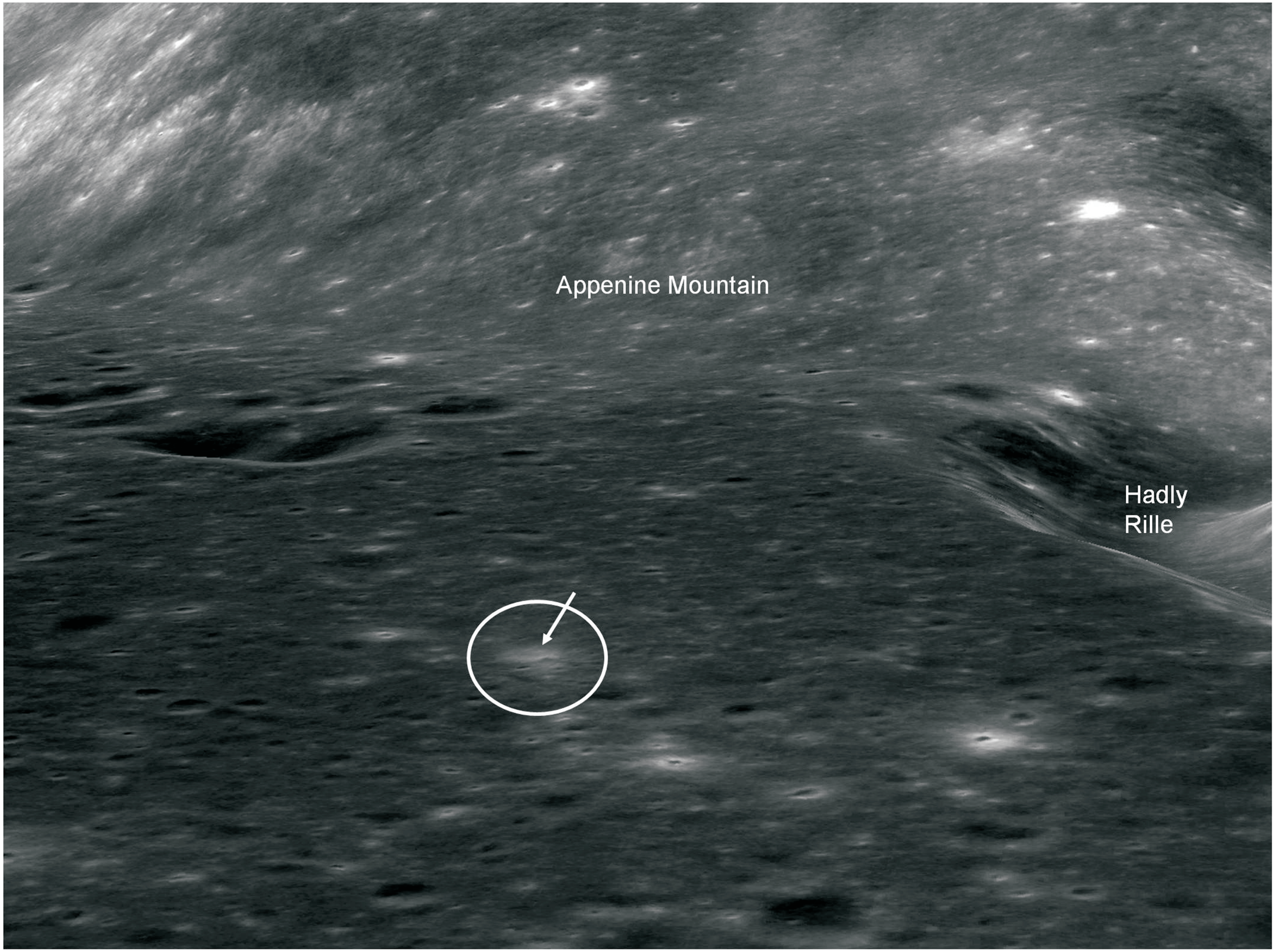


Apollo 15 Landing Site: 2.5D View

The figure is showing a 2.5 dimensional view of the Apollo 15 landing site, near Rima Hadley .
Apollo 15 is the mission for the first time to land beyond equator. The two main primary objectives of this mission are sampling along Appenine Mountains and to explore Hadley Rille, a feature formed probably by volcanic processes. Marius Hills, formed possibly by volcanic structures was also an option for landing in this mission which was rejected later on.

Location : Near Side, Equatorial Region

Orbit :737, Date of Pass :09-01-2009; Image drape view


Appenine Mountain
Hadly Rille

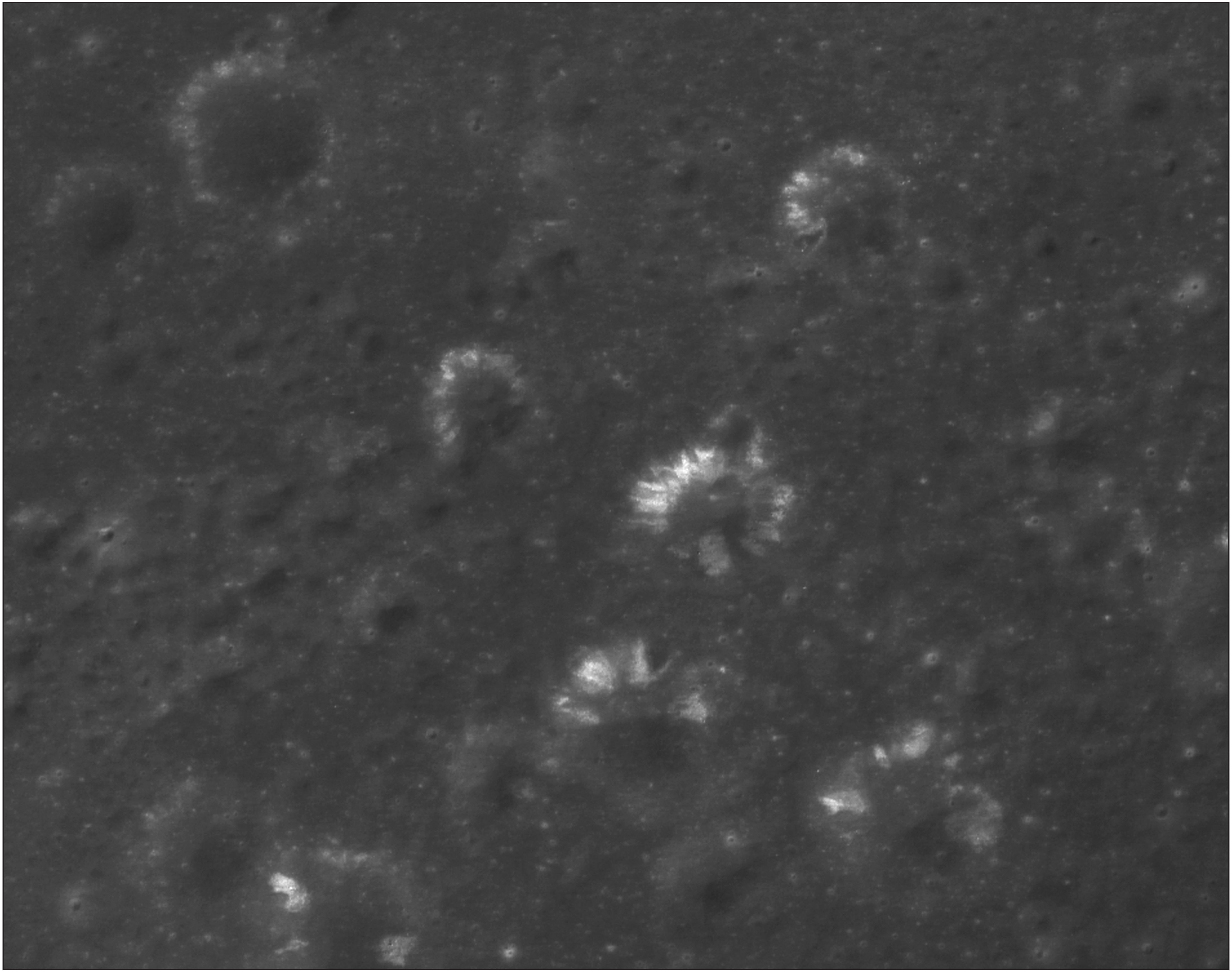
Apollo 17 Landing Site

Apollo 17 was the eleventh manned space mission in the NASA Apollo program. It was the first night launch of a U.S. human spaceflight and the sixth and final lunar landing mission of the Apollo program. The mission was launched on December 7, 1972, and concluded on December 19. It also broke several records set by previous flights, including longest manned lunar landing flight; longest total lunar surface extravehicular activities; largest lunar sample return, and longest time in lunar orbit. The landing site for this mission was on the southeastern rim of the Mare Serenitatis, in the southwestern Montes Taurus. This was a dark mantle between three high, steep massifs, in an area known as the Taurus-Littrow region. The area also contained a landslide, several impact craters, and some dark craters which could be volcanic.

Arrow shows the spot on Lunar surface where Apollo-17 landed.

Location : Near Side, Equatorial Region

Orbit :722, Date of Pass :07-01-2009; Scale – 1:42000;Nadir Image

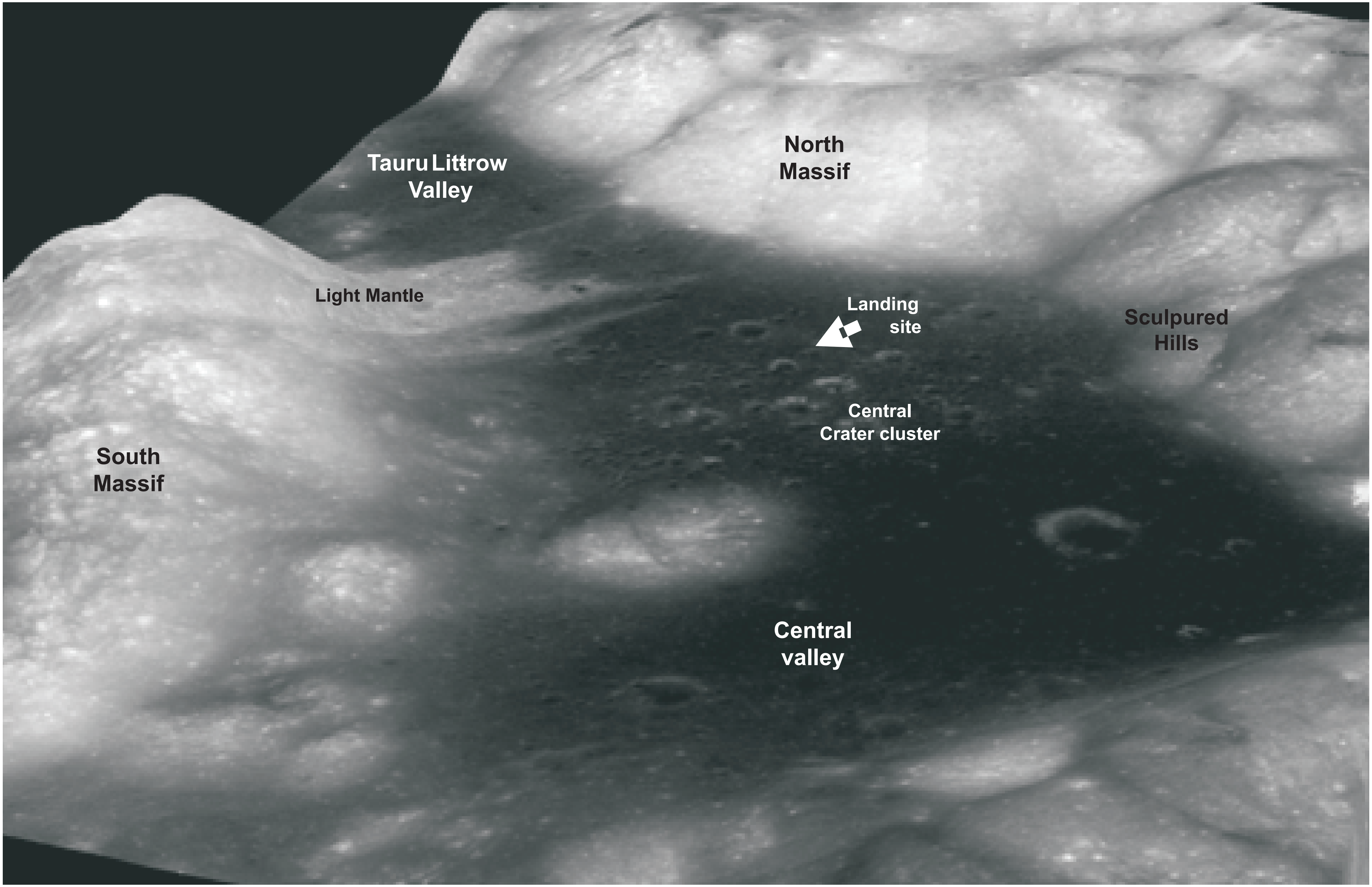


Apollo 17 Landing Site: 2.5D View

The figure is showing a 2.5 dimensional view of the Apollo 17 landing site, Taurus Littrow Valley.
Apollo 17 was a Mission with the highest-priority among the Apollo Missions. The primary objective was sampling of old highland material (older than Imbrium impact and investigating possible existence of Young volcanic material (less than 3 by old). For this mission many a landing sites were opted I.e. near Copernicus crater, near Tycho crater, Tsiolkovsky crater (farside), near Mare Crisium , Alphonsus crater, Gassendi crater but they were rejected.

Location : Near Side, Equatorial Region

Orbit :722, Date of Pass :07-01-2009; Nadir Image drape view


Tauru Littrow
Valley
North
Massif
Light Mantle
Landing
site
Sculpured
Hills
Central
Crater cluster
South
Massif
Central
valley

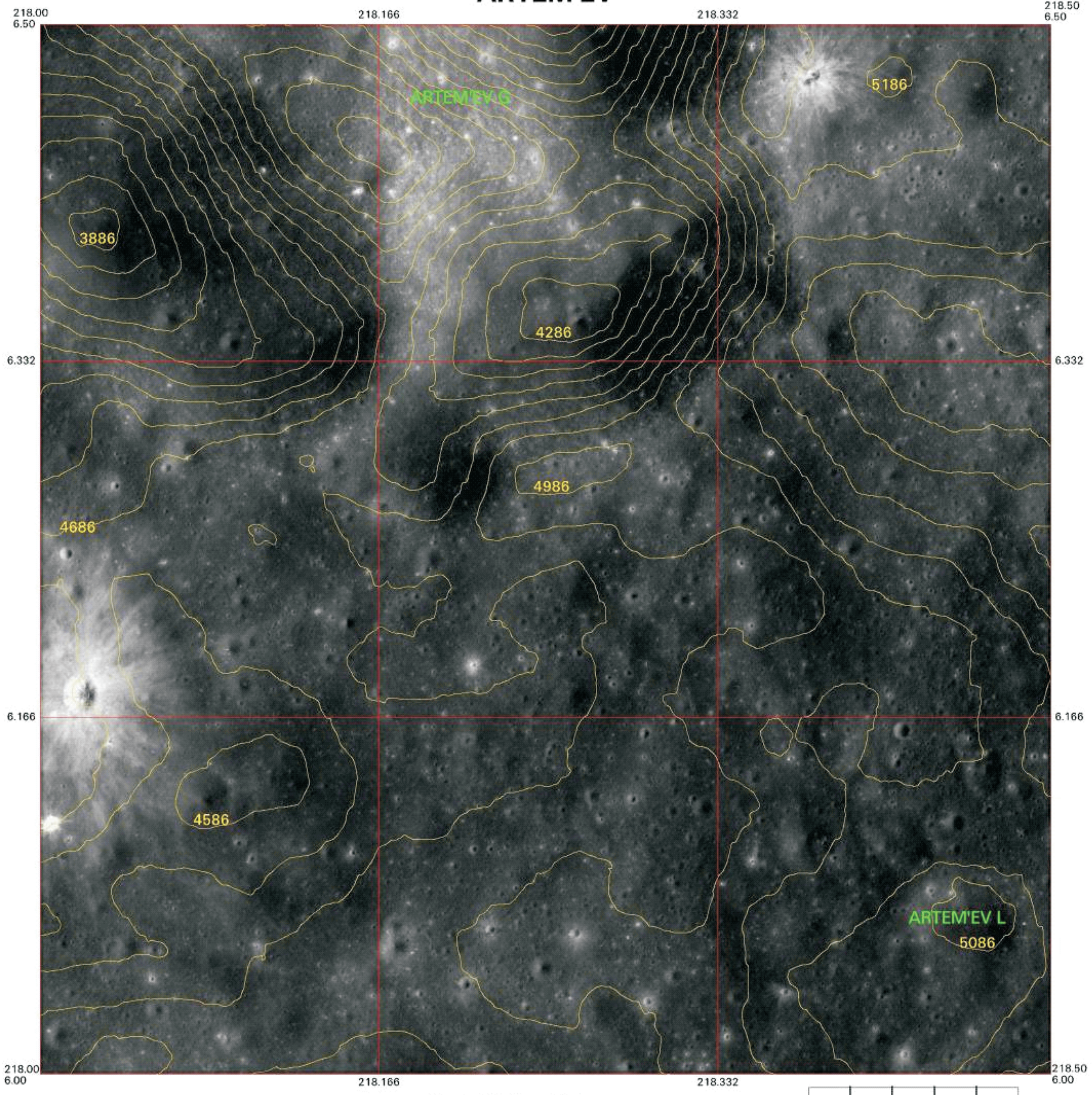
Topographical Mapping

Topographic maps are maps that show locations and elevations of natural and cultural features of a given area. Standard colors and symbols have been designated for use on these maps . Topographic maps are generally oriented to show north at the top. Scales and contour intervals vary on topographic maps depending on the series of the map and the relief (the variation in elevation) of the topography. Topographical maps of the moon from Chandrayaan-1 Terrain Mapping Camera Images are in the process of compilation by photogrammetric methods that use stereoscopic combinations of all the available stereo options. This particular topographical map has been generated at 1:25000 mapping scale with a contour interval of 100 m. The contours overlaid on the map are extracted from the Digital Elevation Model (DEM) generated by Photogrammetric restitution of Chandrayaan-1 TMC triplet. The maps show the names of prominent features (mostly craters) present on the moon Surface. This map followed the mapping scheme and standards prepared by ISRO to prepare gobal topographical maps of the moon at 1:50,000 ;1:250,000 and 1: 1 million map series.

CHANDRAYAAN - 1 LUNAR TOPO ORTHOIMAGE MAP

ARTEM'EV

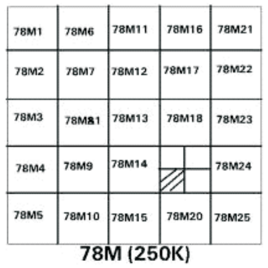
Edition 1 Sheet No.: 78M19SW (25)



Scale (1:25,000)

0 2.5 Kilometers

Contour Interval: 100 m



78M (250K)

Image Information
Data Source: Chandrayaan-1 TMC
Sensor: Nadir
Orbit No.: 876
Date of Acquisition: 20 Jan 2009
Level of Correction: Orthorectified
Projection: Transverse Mercator
Datum: Mean Radius of Moon
Date of Map Production: 10 June 2009
Accuracy: LE = 30 m; CE = 30 m (ULCN 2005)

Generating Agency: Satellite Photogrammetry and Digital Cartography Group
Signal & Image Processing Area; Space Applications Centre, Ahmedabad

INDIAN SPACE RESEARCH ORGANISATION
CHANDRAYAAN-1 TOPO ORTHOIMAGE MAP

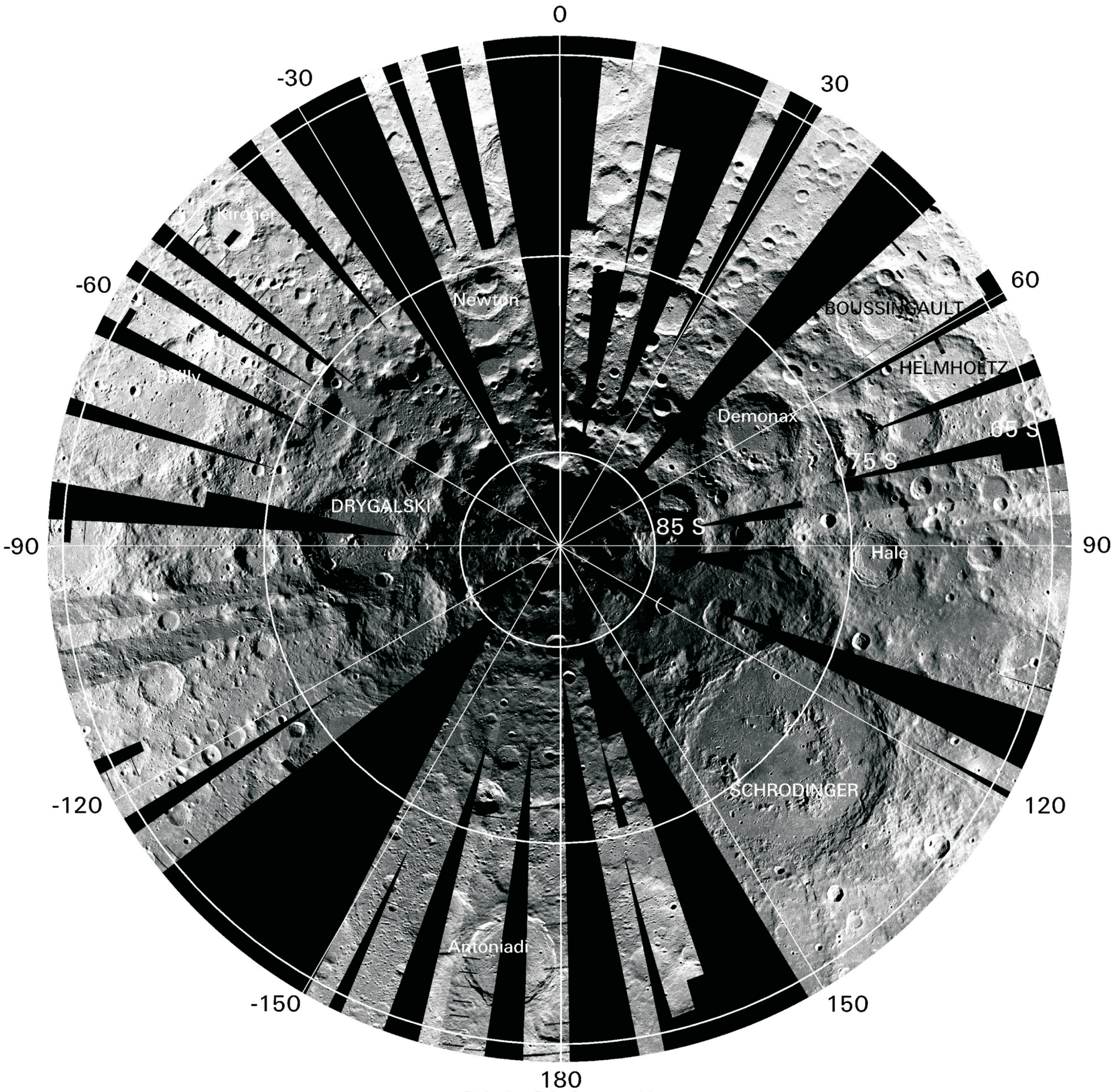
EDITION 1 SHEET No. 78M19SW

Polar Image Mosaics of Moon from Chandrayaan-1 TMC Nadir Images

Chandrayaan-1 TMC has provided largely polar images of the moon during the second imaging season. The activity of polar mosaic generation has been jointly carried out by SAC and ISSDC. This task has two components viz., (i) generation of registered images of all the acquired passes over poles and (ii) mosaicing of the registered imagery, wherever overlap is available between the adjacent passes.

A total of 115 North Pole and 103 South Pole passes stored as PDS datasets were converted from radiance to count product in a tiff image file format. The respective passes from south and north poles are registered to the references (Clementine Polar mosaics) at 10 m resolution by collecting at least 30 lunar control points per pass. These registered images are then sub-sampled to 200 m resolution strips. The automatic method of image matching was then applied for all the 218 passes with respect to Clementine polar image mosaics for matching the edges in the overlap area of two or more images towards ensuring a seamless mosaicing. Three to eight hundred tie points have been generated by the automatic image matching process between each image and Clementine Polar image mosaic. Finally all the images were mosaiced using a common look up table and the defined cut lines among strips. The map projection used for registration and mosaicing is Polar stereographic with the moon spheroid and average radius datum. The final mosaiced image is at 200 m resolution.

IMAGE MOSAIC OF SOUTH POLE FROM CHANDRAYAAN-1 TMC



Projection: Polar Stereographic

Generated By: SAC & ISSDC Teams
Generating Agency: Indian Space Research Organisation

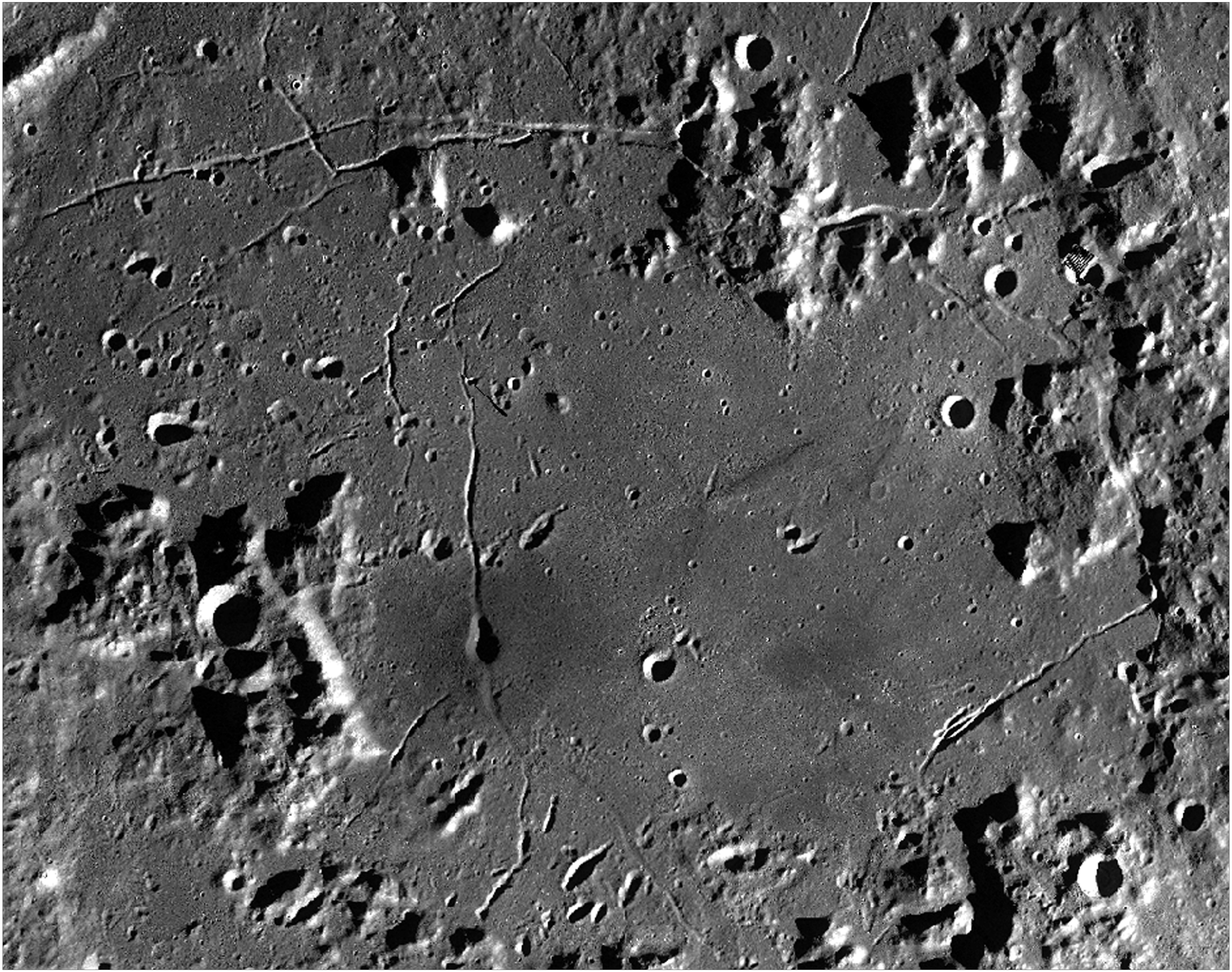
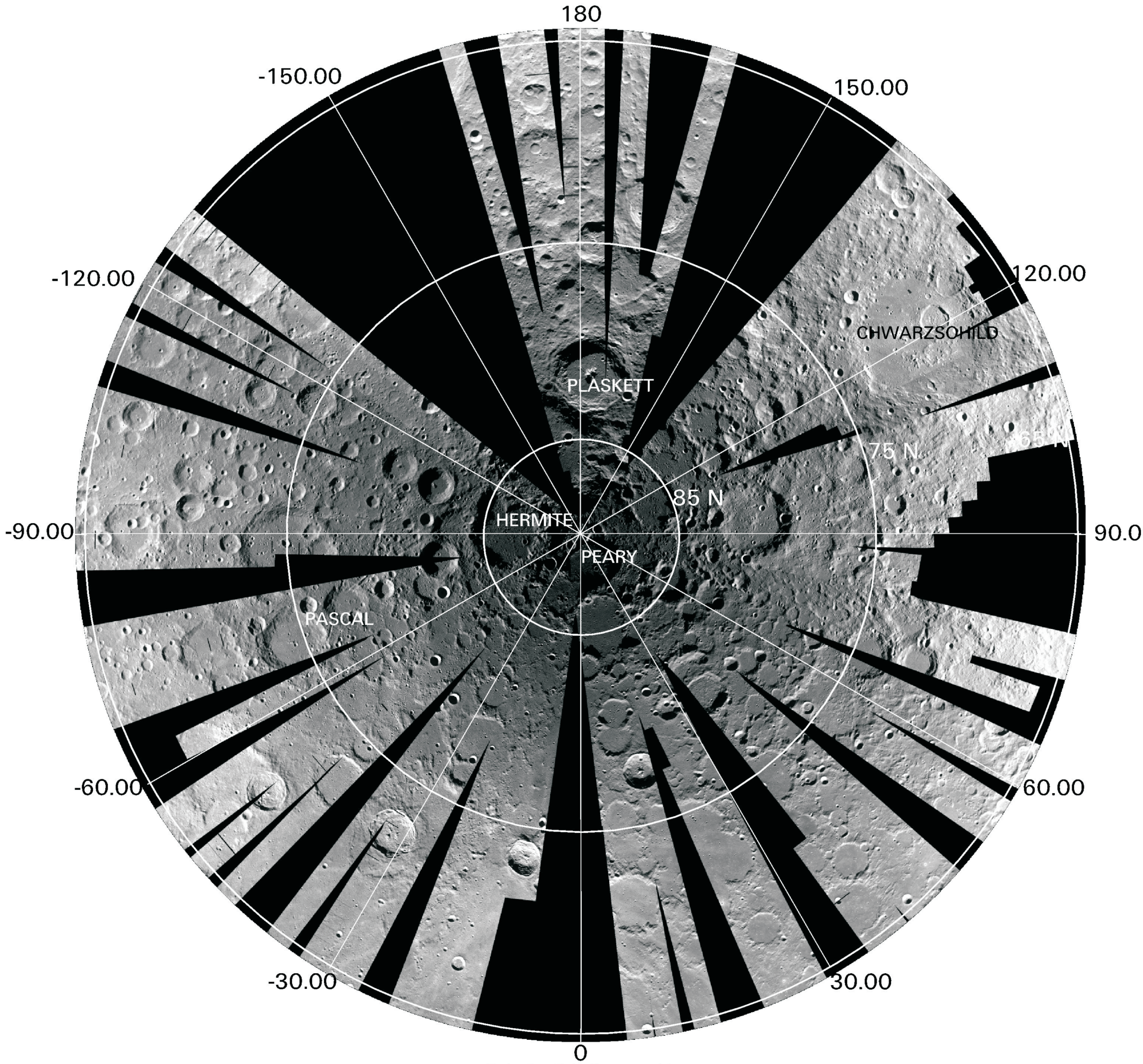
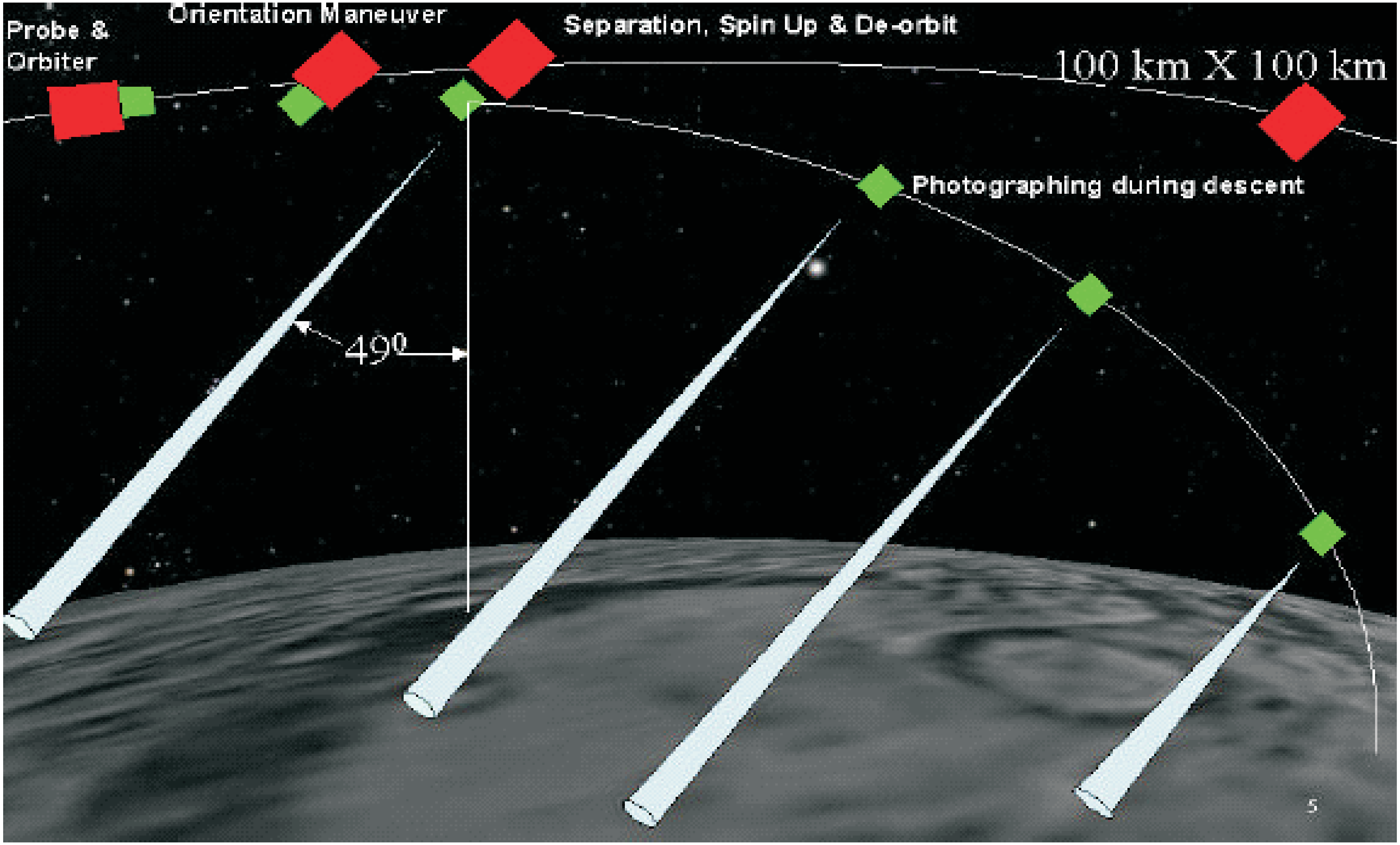


IMAGE MOSAIC OF NORTH POLE FROM CHANDRAYAAN-1 TMC



Projection: Polar Stereographic

Generated By: SAC & ISSDC Teams
Generating Agency: Indian Space Research Organisation


Probe &
Orbiter
Orientation Maneuver
Separation, Spin Up & De-orbit
100 km X 100 km
Photographing during descent
49⁰

Moon Impact Probe (MIP)

The Indian mission to the moon Chandrayaan-1 was launched on 22 October 2008 and it began operations successfully on 14 November 2008. One of the payloads carried by Chandrayaan-1, Moon Impact Probe (MIP), reached Moon's surface on November 14, 2008 at 20:34 IST. MIP housed three payloads viz. Radar Altimeter, Mass Spectrometer and Moon Imaging System (MIS). MIS was a CCD based camera. It operated during the descent to Moon and took 3110 frames. The mission sequence of the MIP is given as

- T0-20 min MIP Power on
- T0-5 min MIP Enable Command from Main Orbiter
- T0 MIP separation
- T0 + 10 sec Spin up of MIP (82.3 RPM)
- T0 + 1489.02 sec MIP impact

Estimation of MIP Landing Point

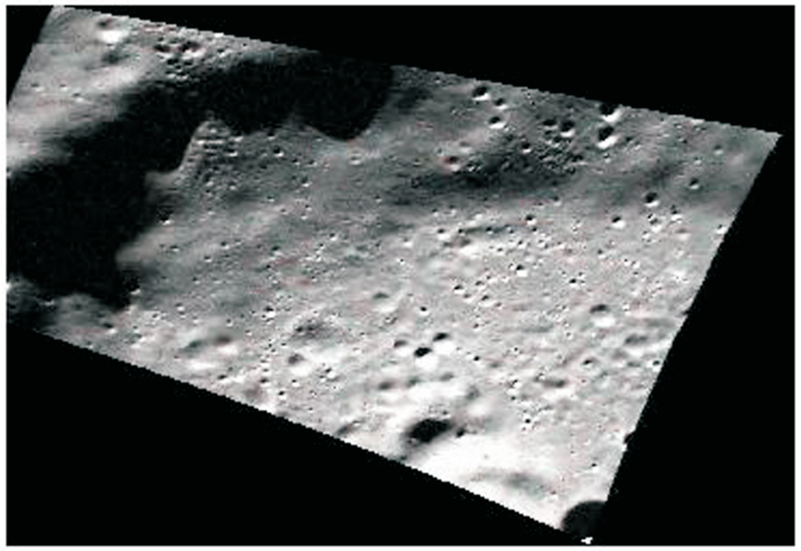
Seleno-referencing of selected frames of MIS images is carried out with respect to the Clementine mosaic with a overlay of available SAR image at poles. After referencing, a cone is created using farthest point at left side and right side of the referenced images on Clementine mosaic. Further, a line is drawn on the surface and centre of the cone, which is followed by the referenced images on Clementine mosaic. The images are falling either side of the centre line or on the line due to the coning of MIP. The impact position is estimated using the distance traversed from first matching position on the polar mosaic to final impact position using the velocity and MTU time.

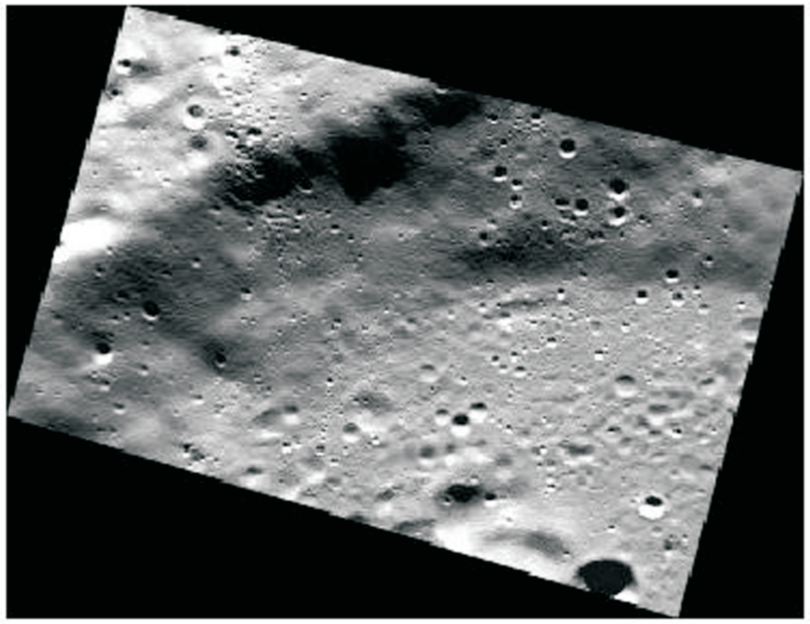
Taking the last matching point (frame number 3099) on the Clementine mosaic as the reference, the last five frames are projected onto the surface of the Moon as per the distances computed using velocity and time difference between the frames. According to the calculations the MIP should have travelled13 km on Moon surface for capturing these five frames. Therefore centre line is extended up to 13 km and a circle of 1 km diameter is drawn for the probable impact site to take into account of uncertainty.

Overview

MIP Images

TMC NADIR Images





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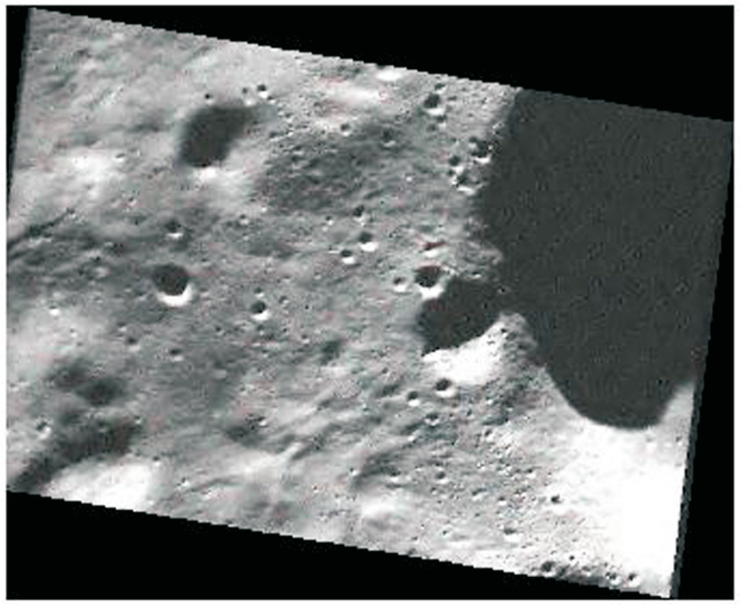

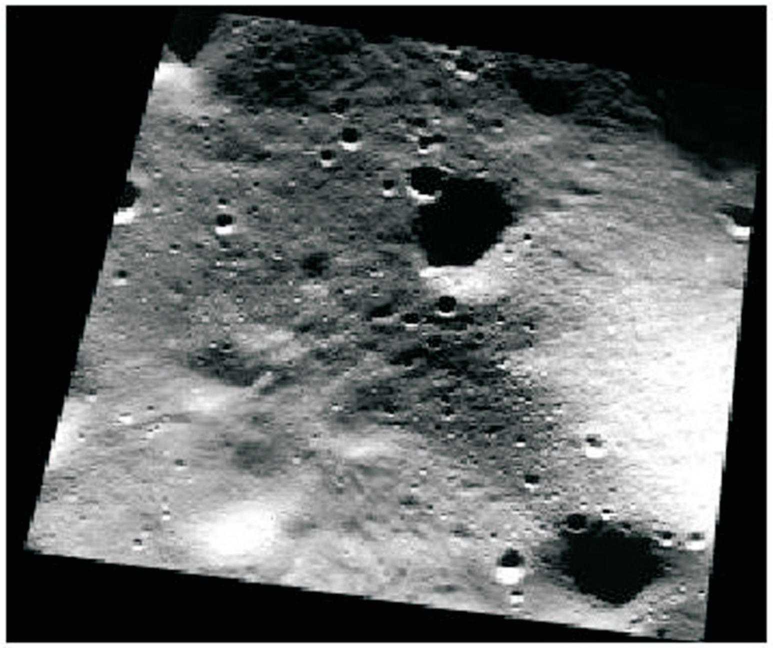

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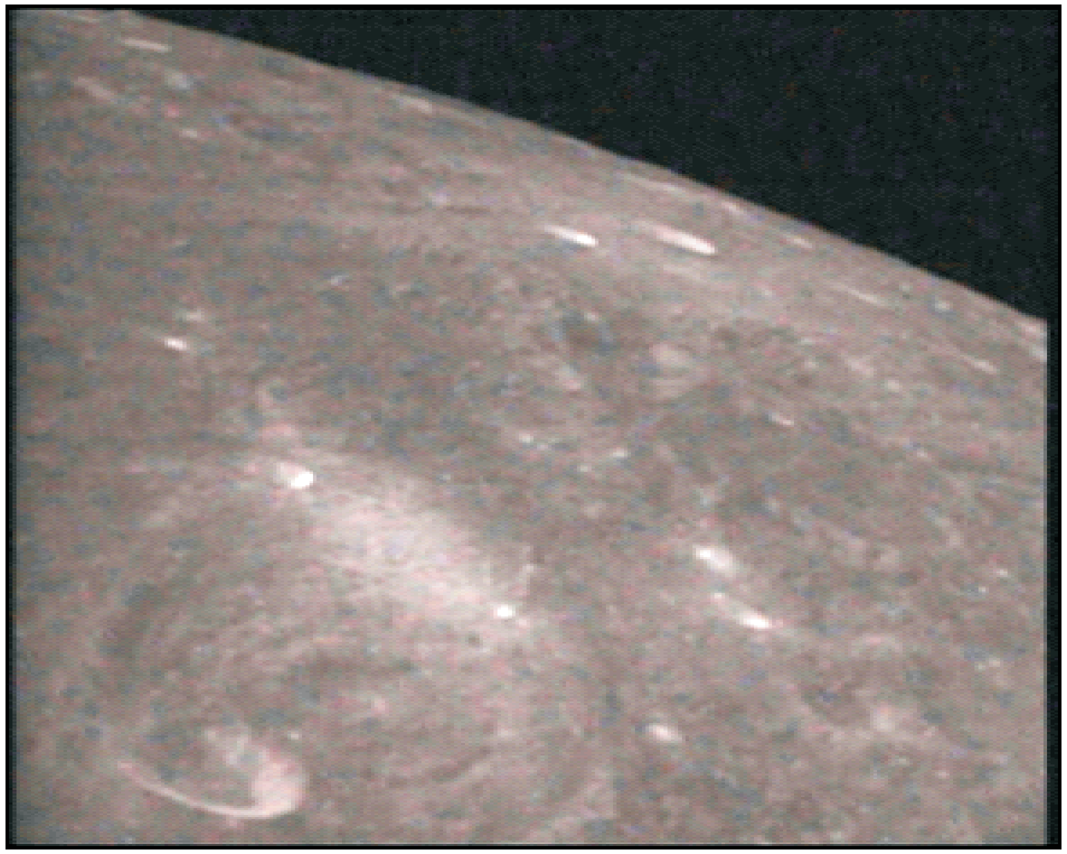
MIP Image Overlaid on TMC Nadir Image: Near Side: South Pole Area

Orbit Number: 2547 ; Date of Pass : 07-06-2009

MIS Frames



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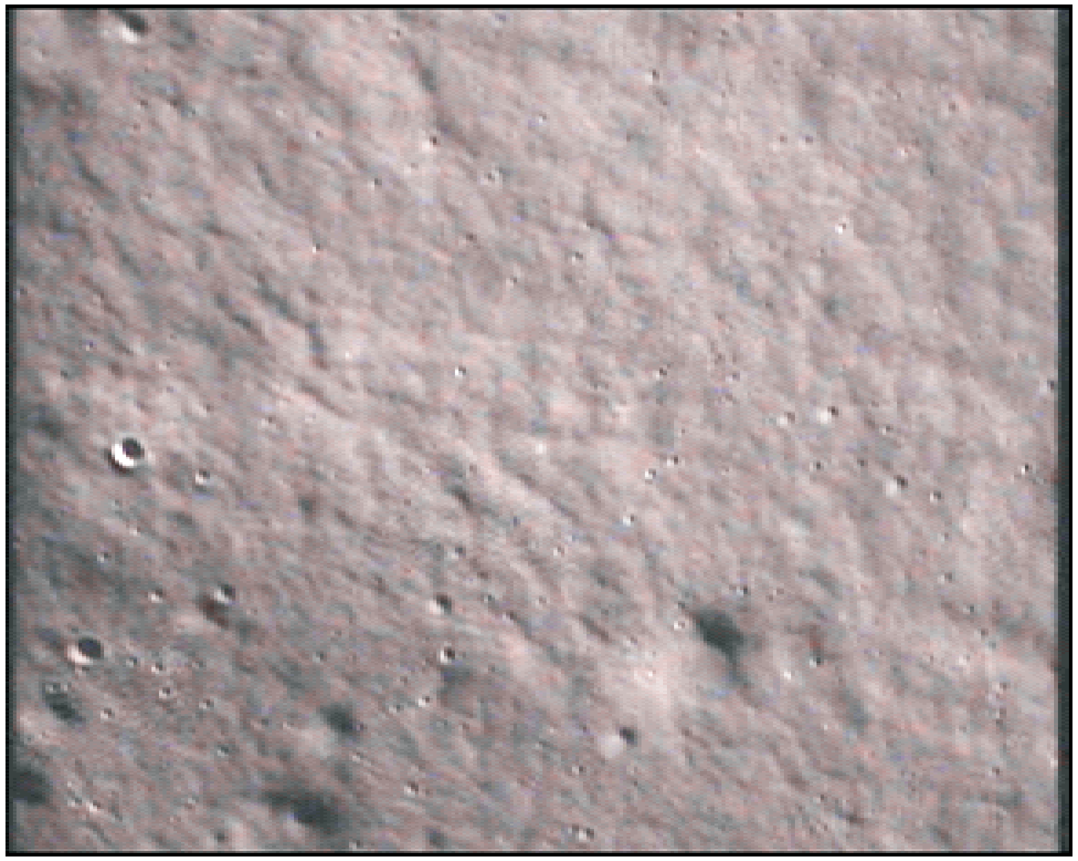

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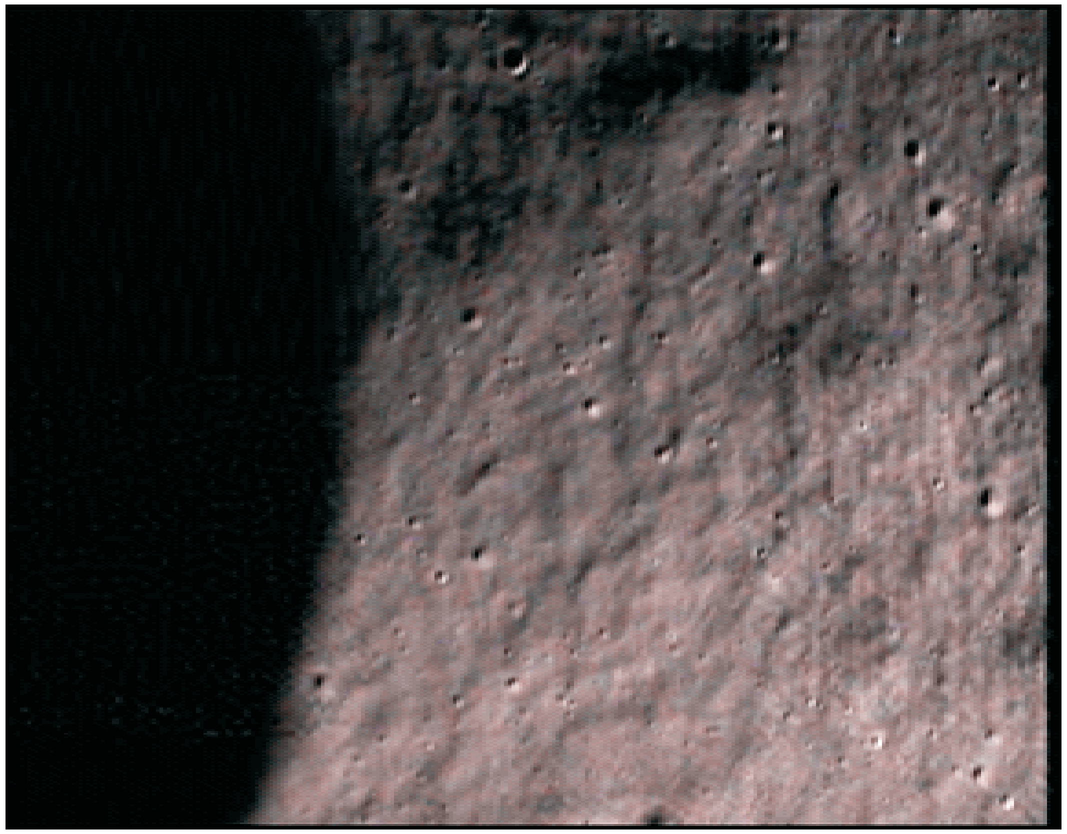

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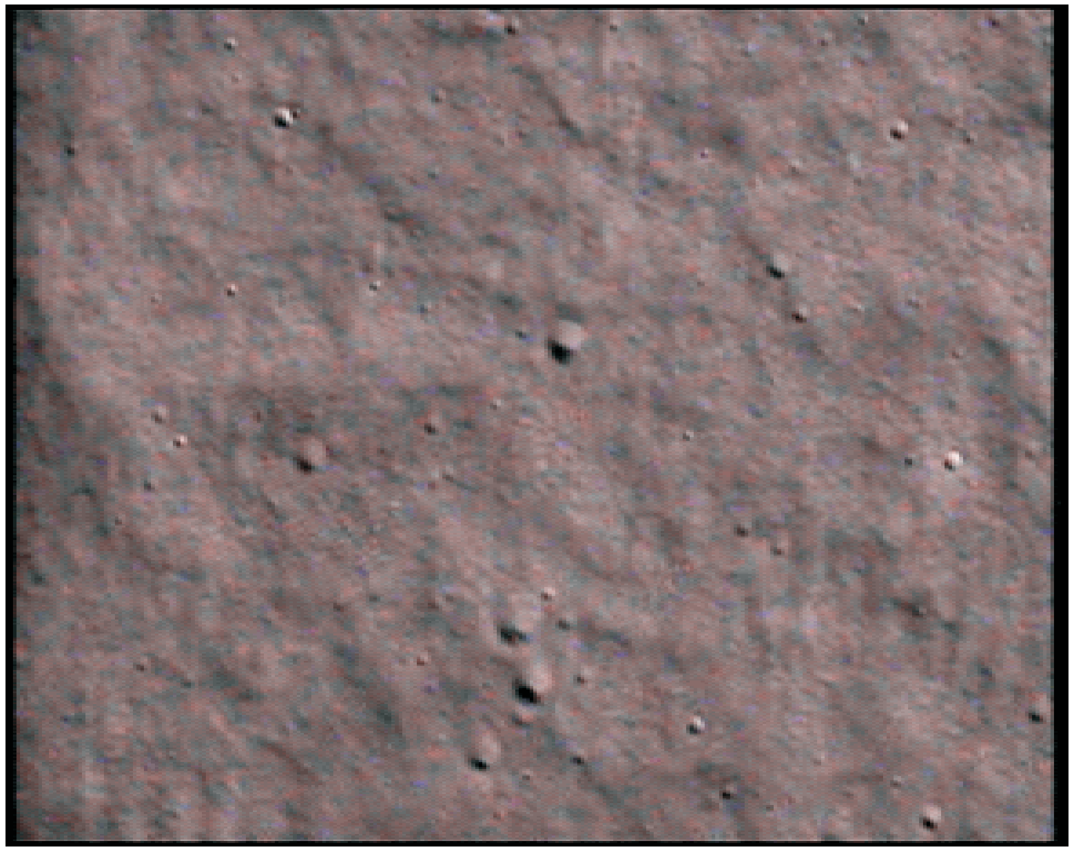
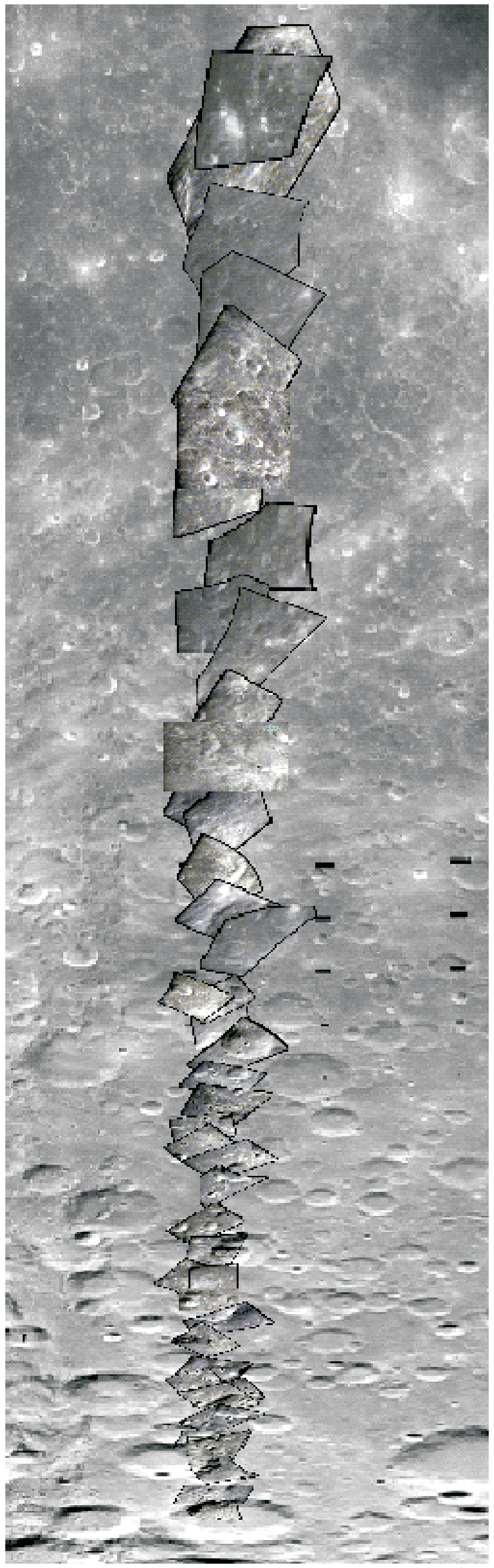
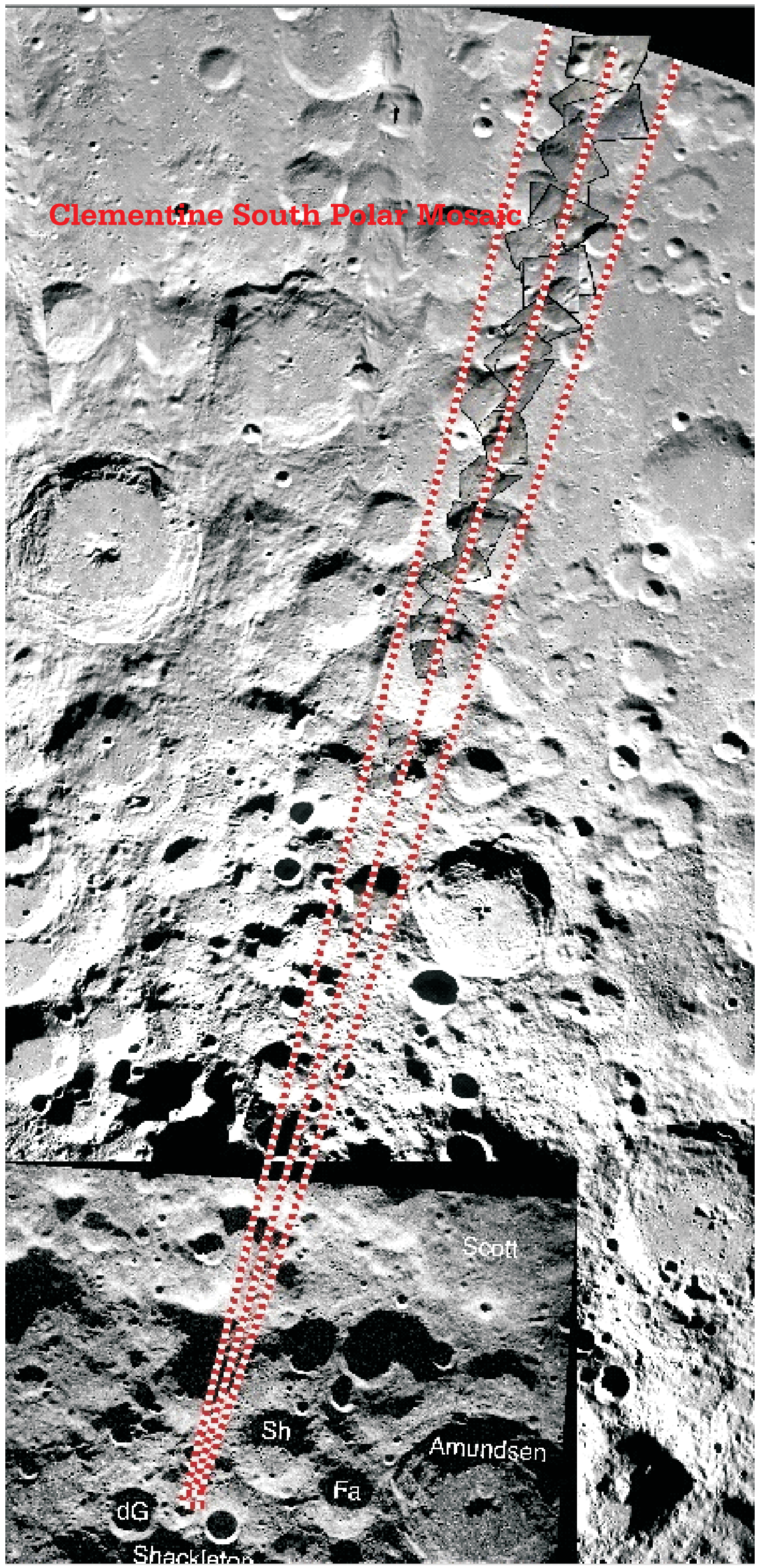
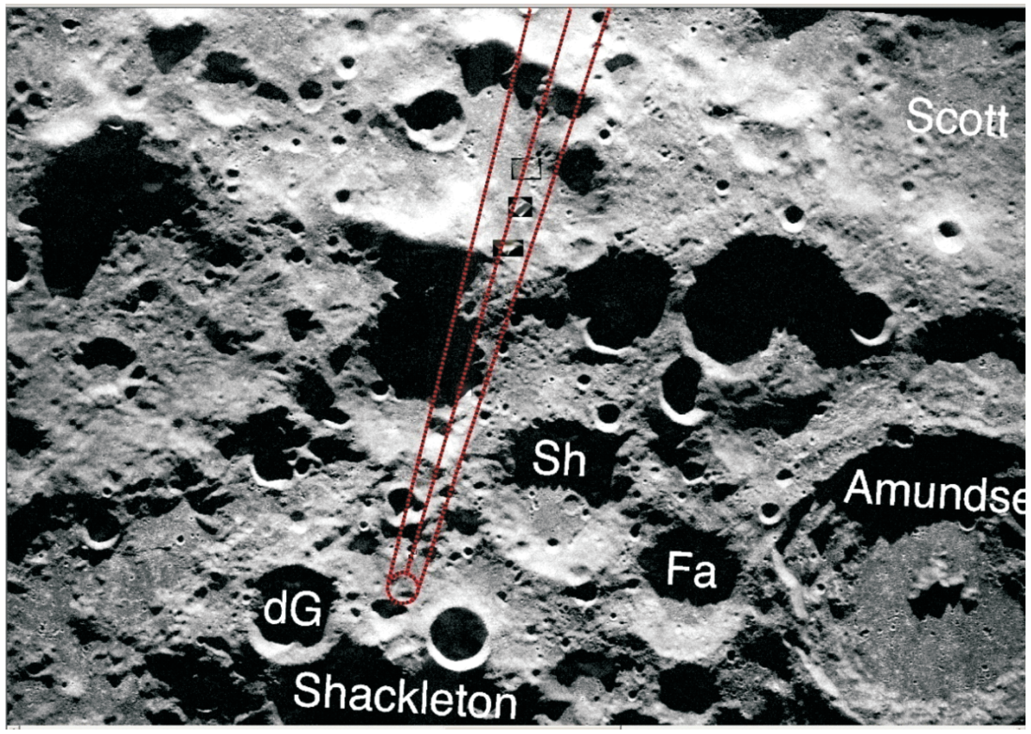


Frame Number - 3105

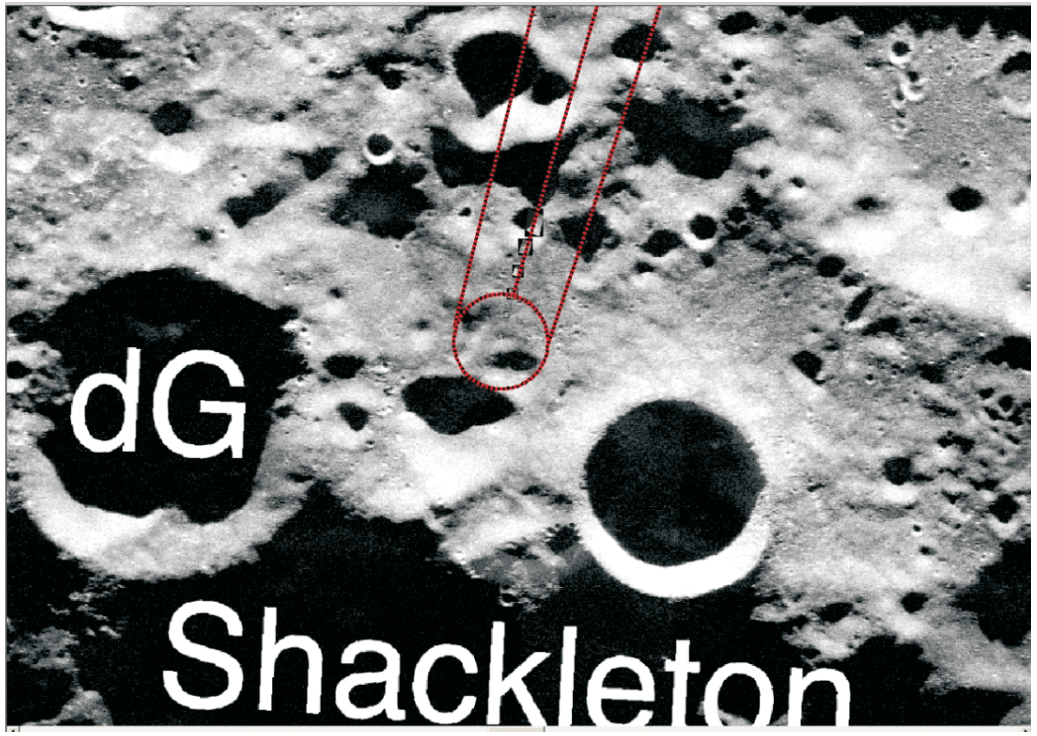
The Moon referencing of MIS images







Portion of SAR and MIS referenced images with probable landing site



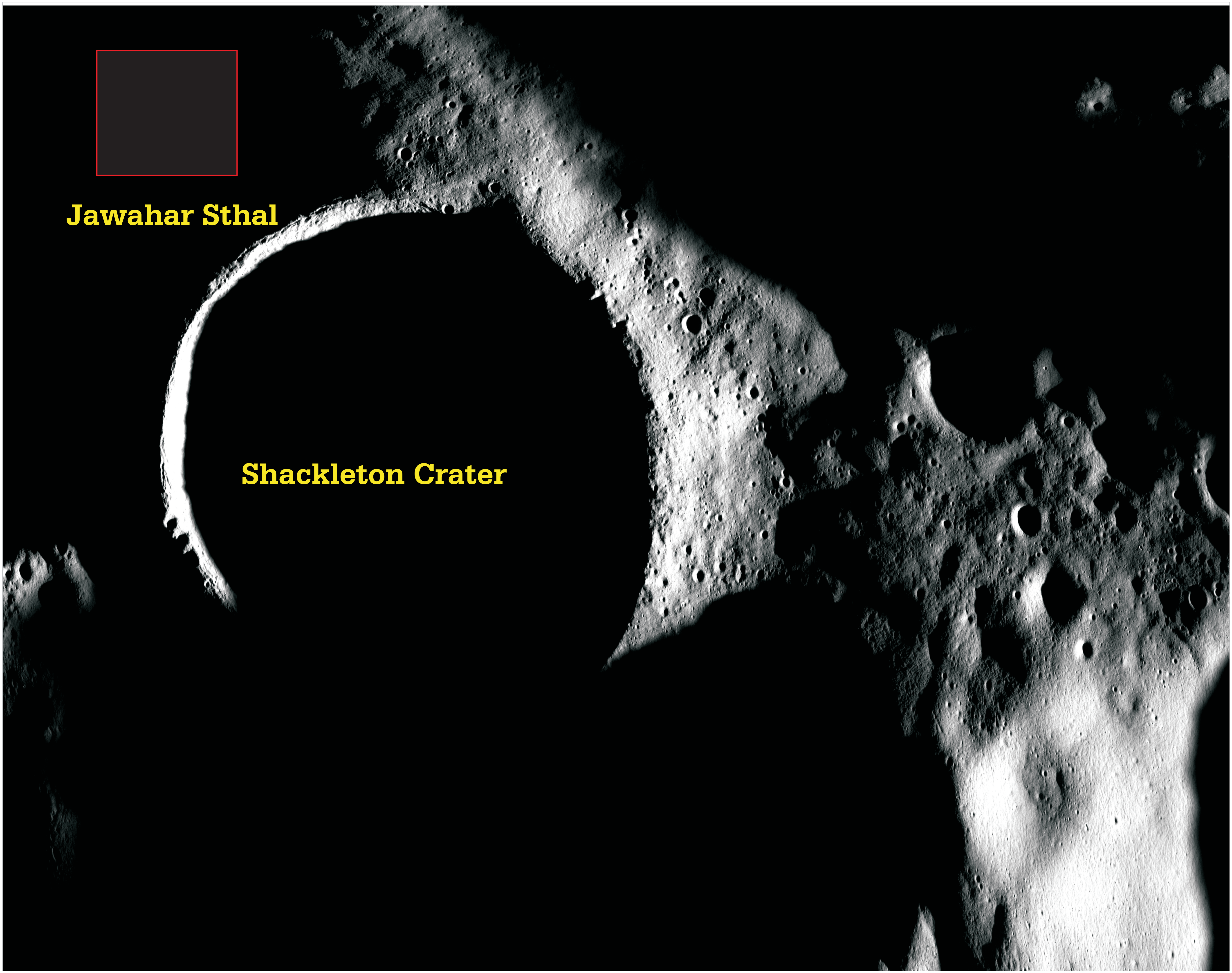
Portion of SAR and MIS referenced image, with uncertainty circle (Diameter- 1 km)

Indian National Flag on the Moon

Jawahar Sthal (Foot Print of Indian National Flag).

Location : Shackleton Crater Area;
Near Side; South Polar region

Orbit no :2792; Date of Pass: 29-06-2009; Scale – 1:224500


Jawahar Sthal
Shackleton Crater

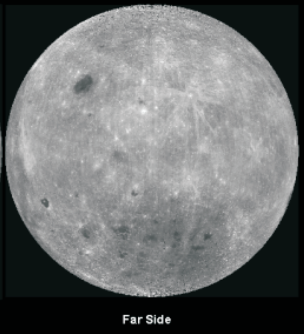
Mineralogical Studies

Lunar surface is mainly composed of two major rock types, i.e., Lunar highland rocks and Lunar mare basalts. A Lunar highland rocks are composed essentially calcium and aluminum rich rocks and appears bright. The Lunar Maria are large, dark basaltic plains on the moon. They are less reflective than the "high lands" as a result of their iron- rich compositions, and therefore appear dark. The Maria covers about 16% of the lunar surface, mostly on the nearside, visible from the Earth. The far side of the Moon is dominated by heavily cratered, light-colored highlands with only a few small, isolated dark maria patches. The lunar highland rocks are mainly composed of low iron minerals such as anorthosite plagiocalse and mare rocks are dominated by iron bearing silicate minerals such as pyroxene, olivine and opaque minerals like ilmenite.

The hyperspectral (HySI) camera onboard Chandrayaan – 1 is used to derive the mineralogy / surface composition of the Moon using spectral reflectance in visible and near-infrared part of electromagnetic spectrum (420- 965 nm).

This section displays some of the studies carried out with HySI data on selected areas related to (i) detection of lunar rock types, (ii) surface composition in terms of Titanium and Iron rich minerals and their distribution, (iii) crater formation and (iv) localised dark mantling deposits

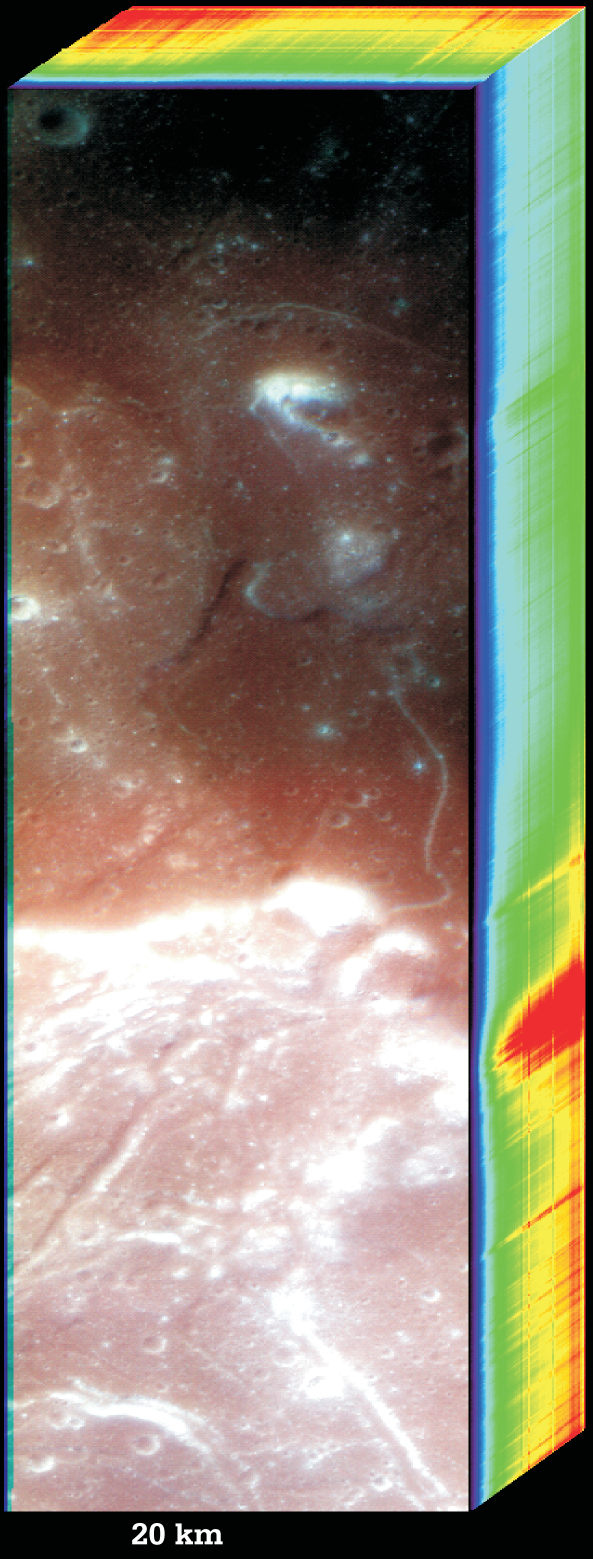
Detection of Lunar rock types using HySI reflectance data for part of Mare Orientale basin

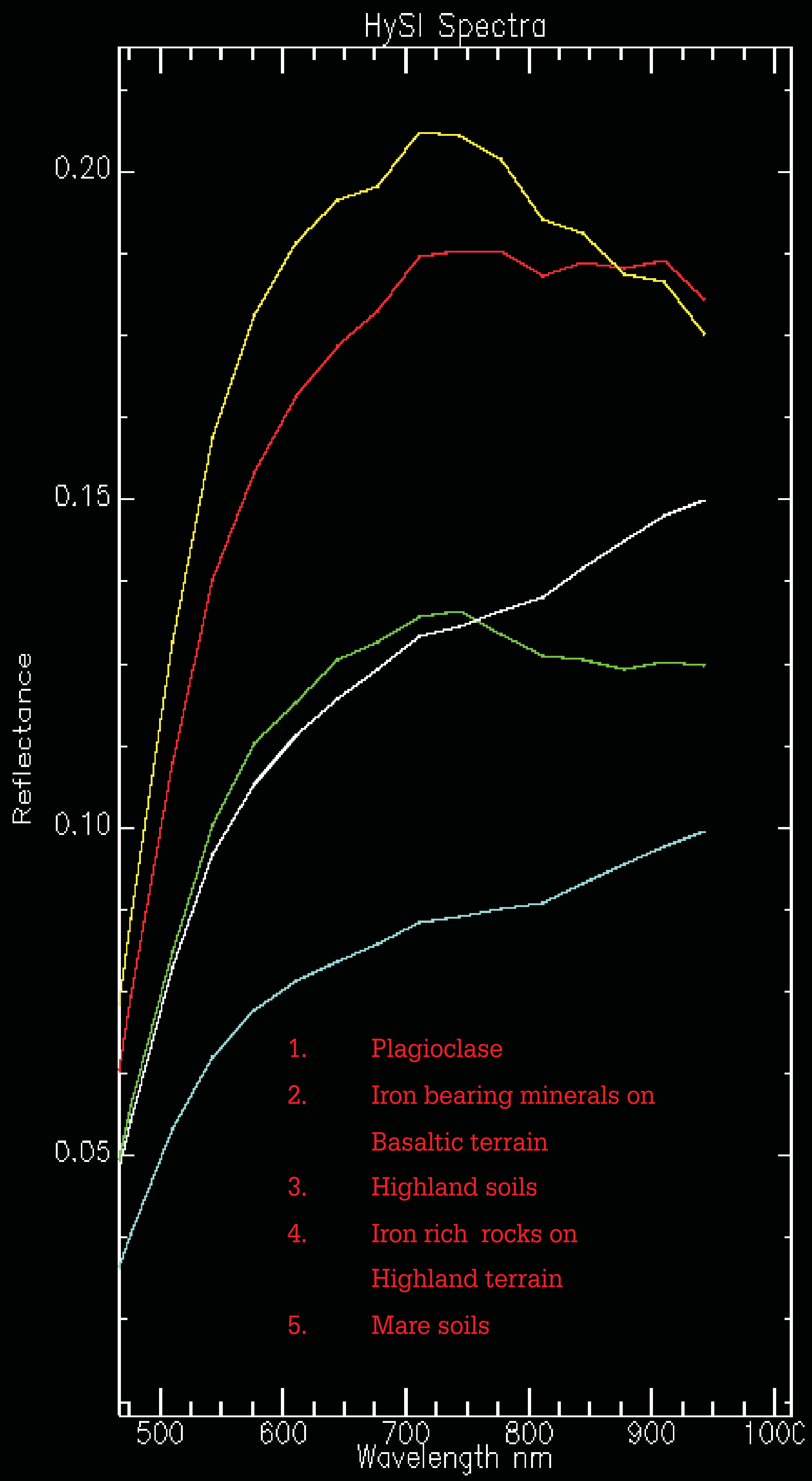


Mare Orientale is one of the youngest basin on the Moon surface. Location of Mare Orientale is shown as red dot on extreme left Lunar composite image.

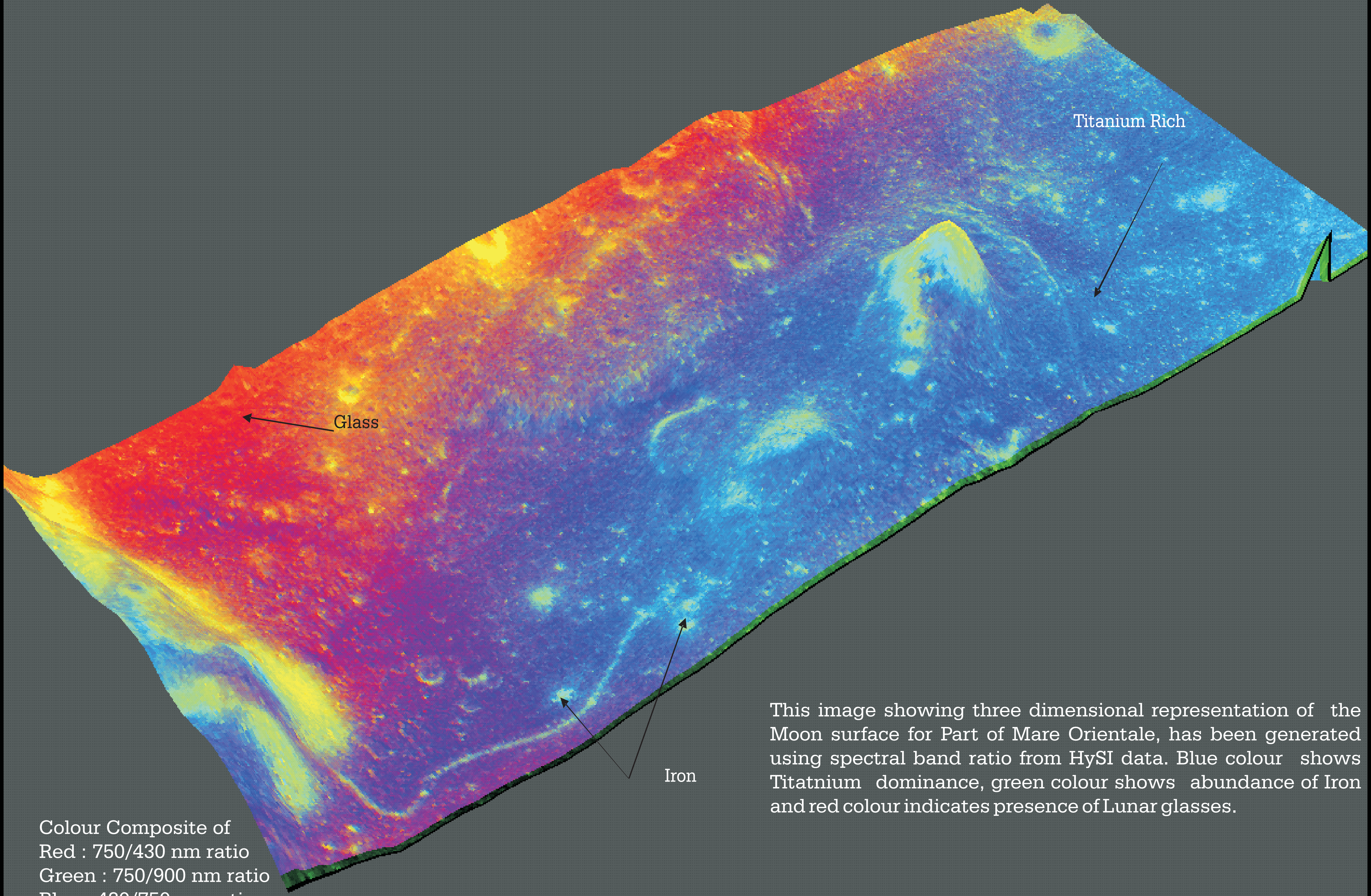
The HySI image from Chandrayaan-1 data represent sixty four colour of Lunar surface. The reflectance curves generated from HySI data helps us to identify highland and basaltic rocks on Moon.

Iron dominated rocks will show up a reduction in reflectance at 900-1000 nanometer wavelengths. In this image locations marked as 2 and 4 show up presence of Iron bearing rocks.





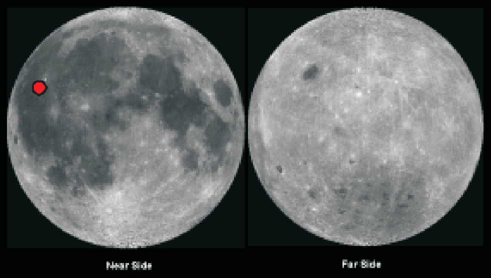
3D view of Orientale basin with HySI derived surface composition showing Titanium and Iron rich regions

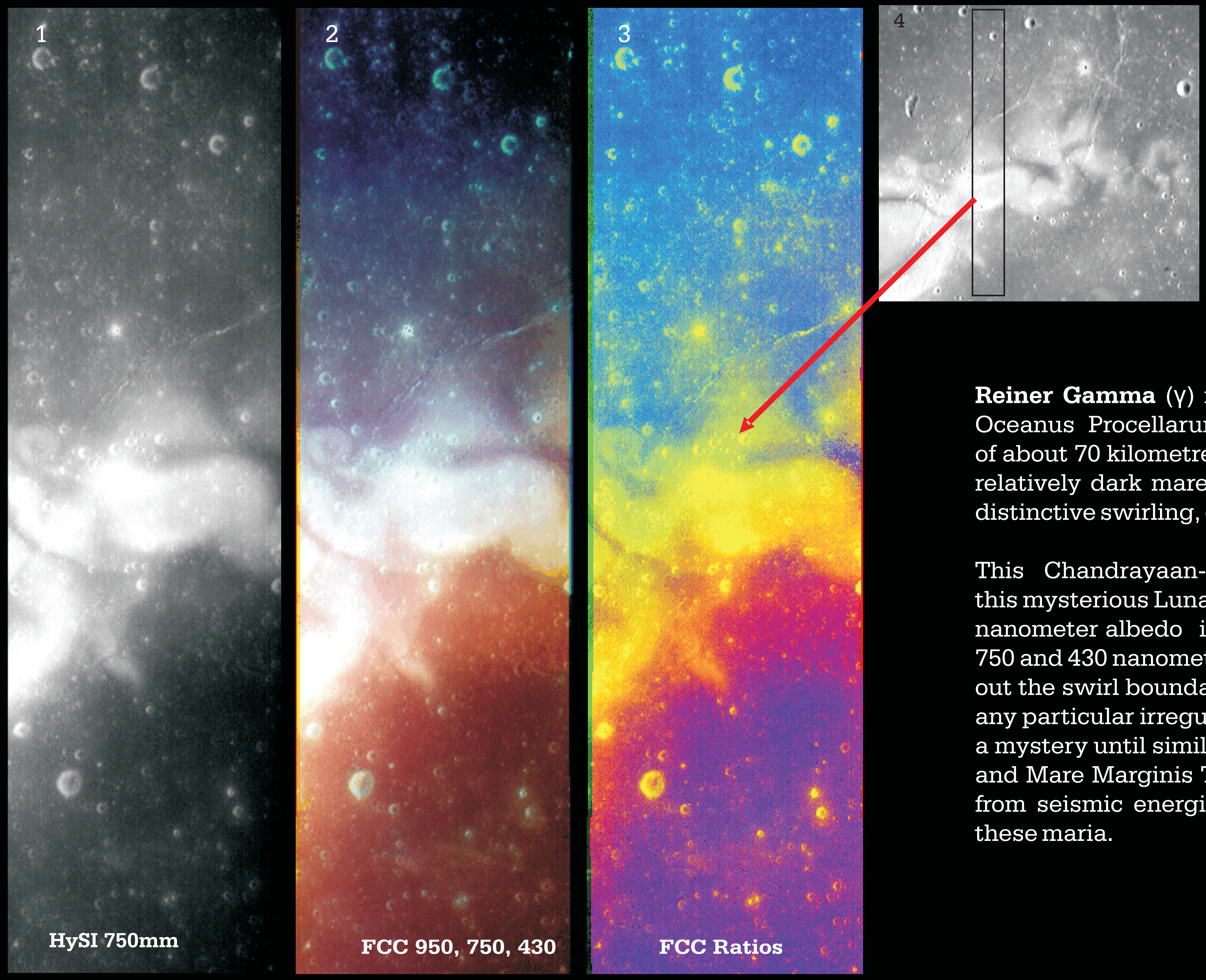


This image showing three dimensional representation of the Moon surface for Part of Mare Orientale, has been generated using spectral band ratio from HySI data. Blue colour shows Titatnium dominance, green colour shows abundance of Iron and red colour indicates presence of Lunar glasses.

Colour Composite of
Red : 750/430 nm ratio
Green : 750/900 nm ratio
Blue : 430/750 nm ratio

Mysterious Lunar swirls : Reiner Gamma Formation





20Km

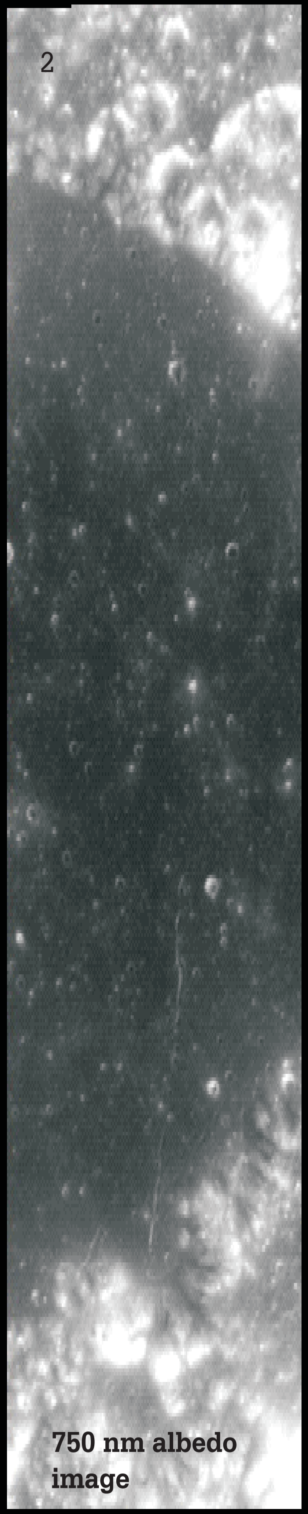
Lunar Swirls

Reiner Gamma (γ) is an albedo feature that is located on the Oceanus Procellarum, on the Moon. It has an overall dimension of about 70 kilometres. The feature has a higher albedo than the relatively dark mare surface, with a diffuse appearance and a distinctive swirling, concentric oval shape.

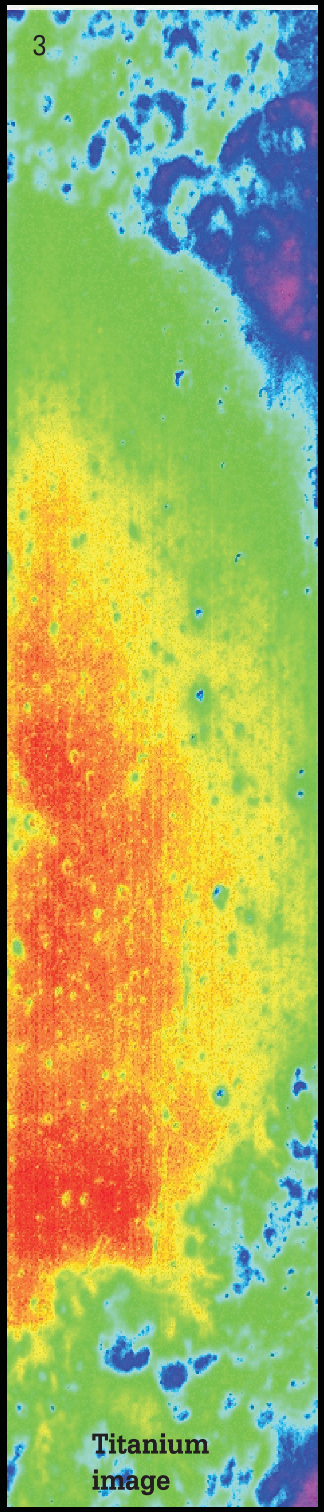
This Chandrayaan-1 image from HySI imager shows a part of this mysterious Lunar swirl (blue box on image 4). Figure 1 is 750 nanometer albedo image, figure 2 is a colour composite of 950, 750 and 430 nanometer images. This colour image clearly brings out the swirl boundaries . Reiner Gamma is not associated with any particular irregularities in the surface, and so the cause was a mystery until similar features were discovered in Mare Ingenii and Mare Marginis Thus it is believed that the feature resulted from seismic energies generated by the impacts that created these maria.

Titanium distribution within Crater Le Monnier, Mare Serenitatis

HyperspectralCube



750 nm albedo image

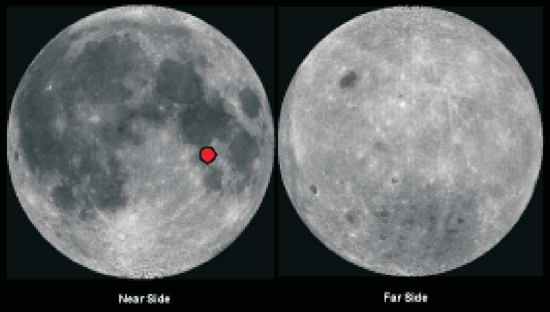


Titanium image

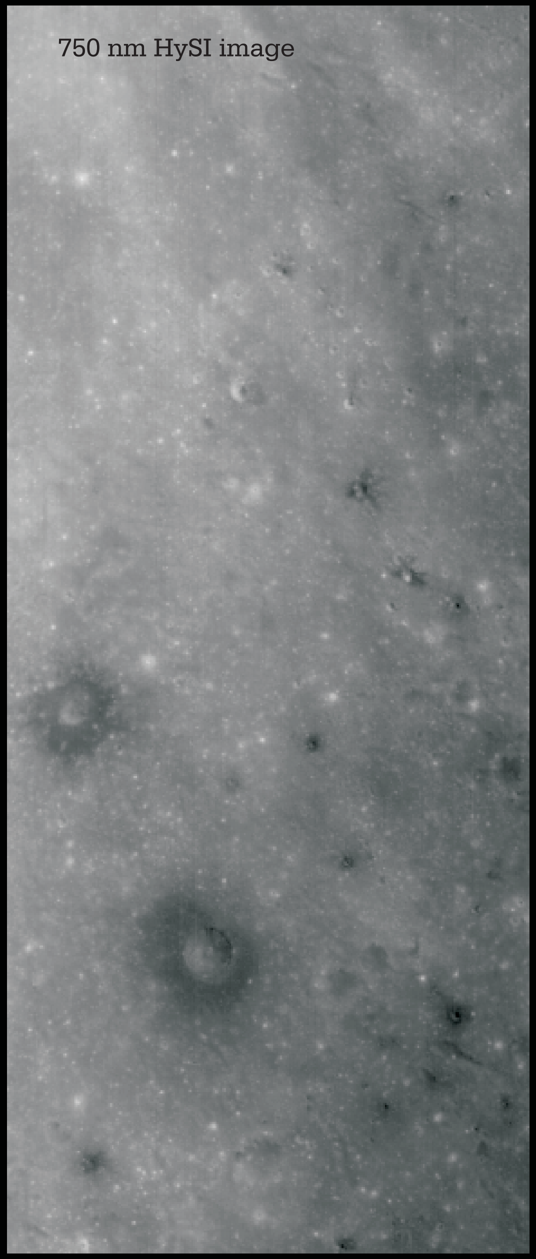
Le Monnier is the remnant of a lunar crater that has been partly inundated by lava flows. It is located on the eastern edge of Mare Serenitatis, and the western part of the rim is missing so that it now forms a large bay. The interior of this formation is relatively flat and smooth. The landing site of the Luna 21 space probe is located near the southern rim of Le Monnier. Lunokhod 2, a robotic roving vehicle deposited on the surface by Luna 21, covered a distance of 37 kilometers across the crater floor. It also surveyed the southern edge of the crater rim.

The HySI image obtained over this crater has been used to study the basaltic composition using the titanium distribution map. Three prominent Basaltic superposition's could be inferred from image 3 showing relatively high (red colour), intermediate(yellow colour) and low (green colour) titanium content.

Relative TiO_2 distribution

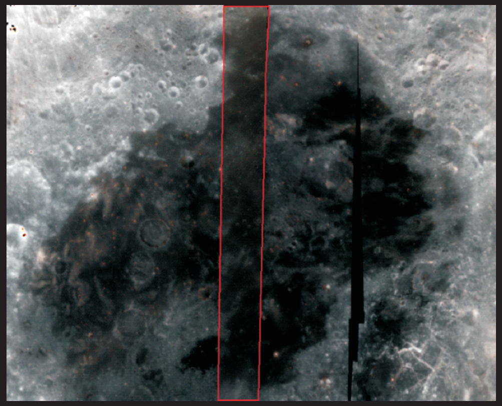


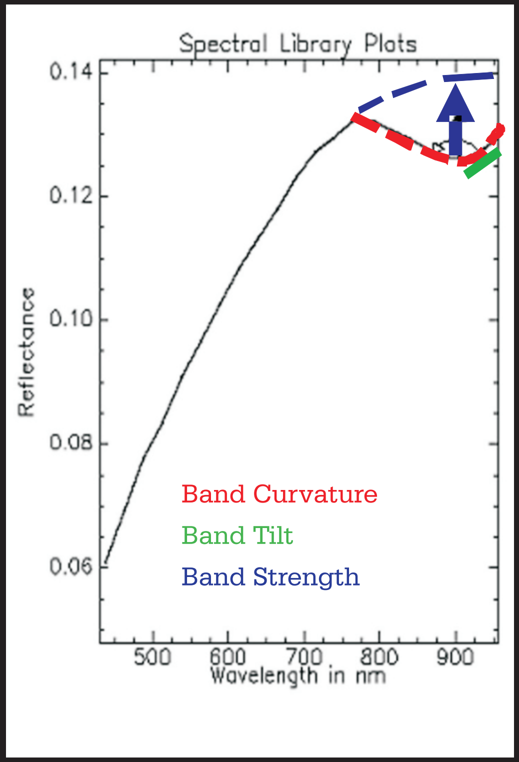
Dark Haloed Craters or Localized dark mantling deposits in Mare Nectaris

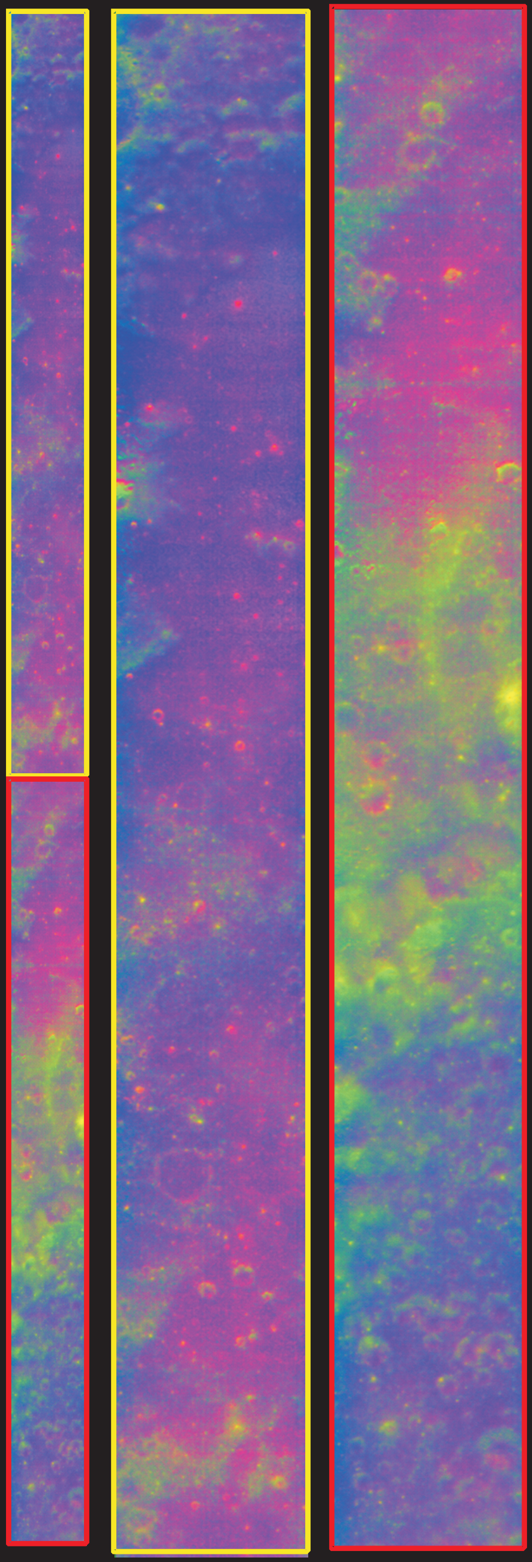


Most of the craters on the Moon surface are bright haloed showing presence of disturbed lunar regolith with reduced space weathering. However, some regions of the Moon surface also contains dark halo craters showing presence of extrusive volcanism in Lunar history.

This image from HySI data over part of Mare Nectaris has captured many spectacular dark haloed craters. One of the prominent crater shows orange coloured regolith material, typical of any fire fountain or pyroclastic deposits.







Mare Moscoviense: A window into the lunar interior

Mare Moscoviense is a lunar mare that sits in the Moscoviense basin. It is one of the very few maria on the far side of the Moon. It is centered within a large impact basin of approximately 445 km diameter and covers an area of 35,000 sq. km.

The great depth of this mare beneath the nearby highlands probably explains why mare units are so rare on the lunar farside. Very few basins on the farside were deep enough to allow mare volcanism. Thus, while large impact basins are found on both the nearside and farside, large maria are mostly found on the nearside. Mare lavas apparently could reach the surface more often and more easily there.

Rock type composite image has been generated using spectral band parameters, namely, band curvature, band tilt and band strength, as obtained from HySI data. Rock type composite depicts lithological variations across the basin. Basalts are shown in green to yellow, norites as red to pink and anorthosites as blue to purple.

Index

Acronyms

ACS	Anticoincidence System
APS	Active Pixel Sensor
ASICs	Application Specific Integrated Circuits
C1XS	Chandrayaan-1 X-ray Spectrometer
CENA	Chandrayaan Energetic Neutral Analyzer
CsI (Tl)	Cesium Iodide
CZT	Cadmium Zinc Telluride
DEM	Digital Elevation Model
EBO	Earth Bound orbit
ESA	European Space Agency
HEX	High-Energy X-ray spectrometer
HySI	Hyper Spectral-Imager
ILO	Initial Lunar Orbit
IO	Initial Earth Orbit
ISRO	Indian Space Research Organization
LEX	Low Energy X-Ray spectrometer
LLRI	Lunar Laser Ranging Instrument
LRO	Lunar Reconnaissance Orbiter
M3	Moon Mineralogy Mapper
MiniSAR	Miniature Synthetic Aperture Radar
MIP	Moon Impact Probe
MIS	Moon Imaging System
NASA	National Aeronautics & Space Administrations
OLO	Operational Lunar Orbit
PMT	Photo-Multiplier Tubes
RADOM	Radiation Dose Monitor
SAC	Space Applications Centre
SARA	Sub ke V Atom Reflecting Analyser
SCD	Swept Charge Device
SIR-2	Infrared Spectrometer
SWIM	Solar Wind Monitor
TMC	Terrain Mapping Camera
TOF	Time-Of-Flight

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